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THE DISCHARGE OF THE MISSISSIPPI RIVER.—CORRESPONDENCE ON PAPER No. 765.*

By F. P. SPALDING, FOSTER CROWELL, T. G. DABNEY, B. M. HARROD, W. G. PRICE, CHARLES H. MILLER, H. ST. L. COPPÉE, J. B. JOHNSON, ARTHUR HIDER, C. McD. TOWNSEND and WILLIAM STARLING.

Mr. Spalding.

F. P. SPALDING, M. Am. Soc. C. E.—It must be apparent to any one who has given much attention to the phenomena presented by the flow of the Mississippi River that the conditions are so variable and the data apparently so discordant as to make any attempt to reduce them to order or to deduce any general laws concerning the flow an almost impossible task. Undoubtedly the laws governing the flow of water are the same for the Mississippi as for any other stream. This, however, does not imply that the formulas for flow of streams as deduced from observations on a small scale are even approximately applicable to this case.

Much time has been wasted in vain attempts to fit the ordinary formula $v = c\sqrt{rs}$, with a coefficient which shall make it applicable in all cases. Notwithstanding the great value to hydraulic science of

* "The Discharge of the Mississippi River," by William Starling, M. Am. Soc. C. E., *Transactions*, Vol. xxxiv, p. 347.

Mr. Spalding. many of these labors, and notwithstanding the value of the formulas themselves for use in general hydraulic work, they still are quite useless when applied to the Mississippi, and, in general, would be more accurate and better for general use if the Mississippi gaugings were not included in their derivations. The common formula $v = c\sqrt{rs}$ is based upon the assumption of a uniform flow at the section considered; that is, upon the absence of any accelerating force, which requires that the water shall have flowed for a sufficient distance in a channel of uniform section to attain a state of equilibrium between the accelerating and retarding forces, a condition which is probably very rarely, if ever, approached by the Mississippi.

The value of s in this formula is necessarily that of the surface in the immediate vicinity of the section under consideration, if the flow is to be uniform under the action of forces due to that slope at the instant of passing the section. The use of this slope in computing discharge by the formula often gives the wildest and most unsatisfactory results. In some cases, as stated in the paper, the slopes may even be negative, giving by the calculation a flow in the opposite direction from that actually occurring.

The use of any formula involving slope for so large a stream is apt to be misleading and unsatisfactory.

The author suggests a method of estimating flow from gauge heights, and it seems reasonable to suppose that an approximate idea may be formed in this way of the probable quantity of water which may pass at a given gauge reading, or, on the other hand, of the probable height on the gauge which will be due to a given flow. This method is certainly preferable to the slope formula, but it is to be remembered that these estimates at best are very rough approximations, and that individual instances will differ widely from the averages used. Whether the river is rising or falling, the duration of the flood stage and the amount of silt carried will affect the result.

The determination of the height to which the water in the lower river would rise if it were confined is therefore a very difficult problem, and the estimates which have been announced for probable maximum flood height under such circumstances are all to be taken with a grain of salt. The Mississippi has a way of adjusting itself to circumstances and of modifying its bed to suit changed conditions which make it reasonable to believe that the estimates quoted in the paper

may be somewhat excessive, and that the effect of entirely controlling the floods would be a smaller increase in flood height. Mr. Spalding.

In regard to the matter of rating meters, it is at least doubtful whether any additional accuracy is secured by abandoning the straight-line formula for ratings and using the curve. The fact that the ratings would form a curve when plotted is not a new discovery, as many observers have been in the habit of plotting them for a number of years, although using the straight-line formula. The straight line may, for the range of velocities commonly met in practice, be made to fit the ratings within the limits of the ordinary errors of observation, and thus introduces no appreciable error into the results. Increased accuracy in discharge measurements must be obtained, if obtained at all, by improving the methods of taking the observations, and not by introducing greater refinements in computation.

FOSTER CROWELL, M. Am. Soc. C. E.—With such a voluminous paper as that presented by the author, it is difficult to single out parts for brief discussion. There are, however, three points which should be emphasized. The first is the inapplicability of the Humphreys and Abbot formula to general use in the gauging of rivers. The author clearly states the reasons for this—reasons which do not appear to have been generally understood by hydraulicians. For instance, Ganguillet and Kutter remark of it: "The American formula is specially adapted to streams with a gentle slope, and is not to be recommended for general application. Nevertheless, it is the outcome of most important studies, and will always retain its high value in its own field." As a matter of fact, it is of value only when used precisely in the conditions it was framed to suit. But for the erroneous assumption to which the author refers, it would correctly represent a particular case. It has already been demonstrated that it gives velocities entirely too small for streams of steep slope, and for streams of flat slope its results vary with the hydraulic mean depth, probably approximating nearest to correctness when the latter is about sixteen. The second point is in regard to the inaccuracy and unreliability of the forms of current meter that have heretofore been employed. They are, as the author has stated, inaccurate, both as machines and in their use. The writer would point out in this connection the importance of selecting properly the gauging places in a stream, so as to avoid the sources of error contained in deflected currents, for which purpose a Mr. Crowell.

Mr. Crowell. separate set of experiments upon the direction of local currents at different depths should be made before the current is metered. The third point is in regard to the effect of viscosity upon the flow of muddy streams, to which the author appears to attach slight importance. In the writer's opinion, here is a fertile field for important investigation, and he hopes at some future day to be able to contribute some results of researches in that direction. Between pure water and thick mud there would be a wide range of velocity for a given slope, and the effect produced by the presence of even a small proportion of muddy matter cannot be disregarded. This question is intimately connected with the movement of sand and gravel, which movement requires work to be done by the stream, reducing its energy and velocity.

Mr. Dabney. T. G. DABNEY, Esq.*—The subject discussed by the author is of the utmost importance to engineers engaged in the practical solution of the Mississippi River problem, and the paper is a most valuable literary contribution to the efforts in the field. It represents the results of a great degree of skill and industrious research in the treatment of a vast collection of heterogeneous data, full of anomalies, real or apparent, from which chaotic store of materials rational laws and valuable practical conclusions have been extracted with great ingenuity and patience. It may be further said that the paper presents in thoroughly digested form that which is of practical value in the voluminous and more or less confused records of observations of Mississippi River phenomena, placing it in available shape for convenient use by river engineers. The principal object of this laborious investigation is embodied in the following paragraph from the paper:

"The immediate object is to find out, first, what was the greatest actual discharge that ever passed down the Mississippi; * * * and, second, what height would such a flood have reached on the gauges of the several stations if it had all been restrained between banks and levees. Better than all would it be to find out the general law regulating the relations of the discharge to the gauge, so that it would be possible, not only to ascertain the height corresponding to the maximum discharge, but to any discharge, at any time, past, present or future. This last quest is the philosopher's stone of the river engineer."

In summing up his final results, the author recognizes the futility of attempting a complete answer to a problem so full of complexities,

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and contents himself with a determination of the maximum discharge at a single station, Arkansas City, as being 1 735 000 cu. ft. per second, and the year of maximum discharge as being 1882, with the extreme gauge height which such a discharge would have produced at that station as being 55.8 ft. if confined between levees. The admitted imperfections in the methods and appliances available for making discharge measurements in such a stream as the Mississippi River forbids the acceptance of actual figures with entire confidence, but it is probable that comparative results are in the main correct, and that the conclusion as to the period of greatest discharge may be relied upon as true. What is of much more practical importance, it is probable that the conclusion regarding the gauge reading for the maximum discharge is correct within a narrow margin. The writer is inclined to believe that this conclusion is rather under than over the truth. Mr. Dabney.

There is only one position taken by the author in his discussion of Mississippi River phenomena upon which the writer ventures to offer a criticism. The author assumes* an alternative scour in the pools and fill on the bars at high stages of the river, with a reversal of these conditions at low or on a falling water. While this is true, it fails to state the whole truth. It is a well-known fact that very large quantities of material are deposited on the bars during high water, but it is a mistake to suppose more than a small proportion of it comes from the bottom of the pools. The river at high stages loads itself to its maximum carrying capacity with material taken from the caving banks in the concave bends, and this would seem to be the source from which by far the greater part of the mass which constitutes the high-water fill on the bars is derived. It follows then, if this be true, that the prevention of bank caving would result in a greatly diminished deposition on the bars, simply from lack of material carried by the current. It is true that wherever caving is checked, either by artifical protection or natural resisting powers of the river bank itself, the suspension of the lateral movement of the channel is accompanied by a transference of current energy from the side to the bed of the river, resulting in vigorous vertical scour. This movement, however, soon reaches its limit, and the quantity of material eroded from the river bed is insignificant as compared with the enormous masses dislodged from rapidly caving banks. The principal efficacy of bank protection, as a means

* See *Transactions*, Vol. xxxiv, p. 428.

Mr. Dabney. of regulating the river's regimen and correcting its numerous evil features, depends upon these conditions.

A large diminution of the material available for deposit on the bars should at once result in a marked increase of high-water depths, a result which ought to be promoted still further by the capacity for erosion of a volume of water with high-water energy and a deficient load, suggesting the probability of an increase of the bar depths by direct as well as negative agency. These conditions should result in a general tendency toward diminishing the disparity between the depths on the bars and in the pools at all stages, with the manifest results of improved navigation facilities and a lower high-water plane.

Mr. Harrod. B. M. HARROD, M. Am. Soc. C. E.—The paper is a full and fair exposition of the difficulties of river discharge measurements on a large scale. Probably these are greater on the Mississippi than on any other stream where gaugings have been attempted; at any rate, as observations of this character have been continued there longer and more systematically than elsewhere, the difficulties have been more fully disclosed, both as regards natural conditions and the methods and apparatus employed.

This river has a width below Cairo varying from 2 500 to 6 000 ft., omitting extremes. Its low-water depth is from 6 to 50 ft. at the bars and pools respectively, and its range from low to high water is 40 or 50 ft. Velocities of 15 ft. per second have been measured. Its curvature is very great, even for an alluvial stream, giving a midstream distance of 960 miles from Cairo to New Orleans, while the direct distance is less than 500 miles; consequently the flow is indirect, crossing about 175 times, from bank to bank, in this distance. These crossings may, at low stages, be nearly at right angles to the trace of the stream. There are vertical eddies, termed boils or whirls according as their movement is upwards or downwards, which have sufficient energy in extreme cases to raise or depress the surface about a foot. The current carries in suspension sand of various degrees of coarseness, small roots and other trash, and on the surface, drift, which is very heavy at the higher rising stages.

The difficulties of gauging the discharge are due to the magnitude of the stream and its turbulence, the horizontal and vertical indirectness of the currents, the rapidity of its changes, and the sand and foreign substances which it transports.

Mr. Harrod.

Evidently the accuracy of a discharge observation increases with the number of stations on the selected section, and the length of time each of these stations can be occupied. On the other hand, since the stage, cross section, slope, velocity, and consequently the discharge, may be constantly and rapidly changing, the observation should be concluded in the least possible time. It seems reasonable under these conflicting demands, that for the best results an entire discharge observation should be accomplished during a single working day. Within this limit, all possible detail should be crowded.

Discharge observations have been of two classes on the Mississippi. Whenever certain conditions, generally of high or low water, occur, which promise important results, local observations are made along those parts of the river where the greatest amount of work is being done, or where the greatest changes are expected. Again, a series of stations have been selected on several occasions for occupation for an entire year. This latter system would give the best results under favorable conditions, because the entire movement from low to high water and back again, over the whole river, would be observed by specially organized and practiced parties using similar instruments and methods. As such an organization must be determined on some time in advance, and as its cost is from $75 000 to $100 000, and as the year selected may not prove eventful in the sense of there being extremely high or low water, the undertaking involves risks and therefore has not been repeated as often as is desirable.

The discussion between double floats, rods and meters is still open, and the writer does not propose to close it. On the Mississippi, the merits, defects, and particularly the limitations of the two former devices, are well ascertained. While their demands on the intelligence of the observer are less than those of the meter, they are not less on his care and conscientiousness. With double floats not only may the sub-float be raised several feet, as noticed in the paper, but the surface float may be submerged, as the vertical eddy in which they are involved is moving upward or downward. The ways of the lower float may be as devious and obscure as those of the meter, giving all sorts of relations to its surface companion. With the rod the small part of the depth which its limited length can integrate, and the doubtful and varying relations between velocities and depths leave much uncertainty in its results.

Mr. Harrod. These two instruments are so simple and have been in use for so long a time without material change that it is hard to see how they can be made more useful on the Mississippi. While the meter is much more complicated, its evolution is of recent date and is still going on. The exigencies of the Mississippi River service have led to a form which withstands hard usage, has bearings protected against sand and grit, and is not readily encumbered by small roots, leaves and other trash, but is still highly sensitive. It certainly requires great care and skilful manipulation. Its failure to record the direction of currents as well as their velocities is a serious defect, which is, however, shared in a degree by both double floats and rods. Should the direction meter which is now being introduced prove adaptable to the conditions in the Mississippi River, it would appear that there is hope for progress in the art of gauging great streams in the perfecting of this instrument and its expert use.

It seems probable that greater use of the method of integration, both vertically and transversely, would detect movements which are likely to escape the observations ordinarily made, and eliminate errors which may be involved in an assumption of fixed relations between velocities at different points in a cross-section.

The part of the subject discussed on pages 420 and 422* of the paper is of extreme interest. Selecting the year 1887, "because it was not a year of very great flood, nor, therefore, of great disturbance of high-water conditions, and because it was a year of very low water," and also because sufficient levee building had not then been done to affect materially the characteristics impressed on the river during its long unleveed condition, the range from low to high water at the mouths of the tributaries and at intermediate points is found to be as follows:

Cairo	46.35	Mouth of the Ohio River.
Belmont	40.99	
New Madrid	37.14	
Fulton	32.38	
Memphis	34.10	
Helena	46.15	Mouth of the St. Francis River.
Mouth White River	44.25	
Arkansas City	46.35	First gauge below the Arkansas River.
Greenville	38.95	
Lake Providence	36.48	
Vicksburg	48.61	Mouth of the Yazoo River.
Natchez	43.45	
Mouth Red River	42.53	

* Vol. xxxiv, *Transactions.*

Mr. Harrod.

Bars with 6 to 8 ft. of water recur with sufficient frequency to make the low-water surface conform to the general shape of the bed. In plotting the high and low-water surfaces, it is clearly observable that the former present a more regular curve, and that the irregularities of the latter consist of depressions at and about the mouths of the tributaries, with elevations at intermediate points.

If the beds of sedimentary streams are self-regulated, as is stated by the author and generally accepted by engineers, then the variations of discharge between parts of the river where it is augmented by the volume of the tributaries and the return of the overflow, and those parts where it is depleted by escape into the basins, may be reasonably accepted as a cause of the depression of bed where the discharge has been habitually increased, and of the elevation of bed where loss by overflow has been unchecked for a long period of time. If this relation of cause and effect exists, then, if the discharge is confined to the bed and not allowed to escape over the banks, and is thus made uniform throughout the length of the river, with the exception of the additions from the drainage from the tributaries, the bed should become quite uniform in depth and cross-section, with an increase below each tributary, proportioned to its discharge.

The confinement of the high-water discharge to the bed is now being effected by levees on some parts of the river. These artificial banks have not yet the height necessary to restrain the greatest floods, but since 1891 they have been able to hold them at a considerably greater height than ever before. It is important to ascertain if this increased restraint of flood discharge is producing the effect anticipated. At present there is no conclusive evidence on this question, but the indications are that the deposits between tributaries are being removed by the greater uniformity of flood discharge caused by the prevention of overflow. Where levees have been improved and the flood discharge increased, its height is not proportionately raised. The effect, so far, seems to be divided between a higher surface and a lower bed.

If a general summary is made of the gauge records from 1882 to 1894 inclusive, they can be classified, as regards time, into two divisions, from 1882 to 1890, and from 1891 to 1894. They may also be divided locally, from Cairo to Helena, and from the White to the Red River. This division in time agrees substantially with the beginning

Mr. Harrod. of effective levee progress, and the division in locality is between those parts of the river which are unleveed or leveed on both sides. If, with these divisions in mind, the mean of the low waters over the entire period, from 1882 to 1894 is considered, it will be observed that for the years since 1890 they were lower through the entire river below Cairo than in the earlier years; but it will be observed further that while the mean relative depression where no effective extension of the levee system is yet made, or from Cairo to Helena, is 2.89 ft., from the White to the Red River, where greater levee progress has been made, the depression is 4.46 ft., or 1.57 ft. more.

If the mean of the low waters of the years previous to 1891 are compared with the low water of 1894, it appears that while the relative depression in the latter year in the upper or unleveed part of the river was 4.88 ft., in the lower or leveed part it was 7.41 ft., or 2.53 ft. more.

The period during which the river has been the subject of observation and work is too short to give definite conclusions, but the tendency shown in the foregoing statement, and by other indications, is quite marked for the limited time considered.

Mr. Price. W. G. PRICE, M. Am. Soc. C. E.—In the work of measuring the discharge of a great river most of the errors are probably due to eddies and cross-currents, and to a lack of skill on the part of the observer. Discharge sections should be located where the flow is most uniform. A section near the lower end of a straight reach will generally give better results than one just below a bend. Much inaccurate work has been due to imperfect meter ratings. After a meter was rated, the observer had no way of testing his work, except to rate it again, and, owing to a lack of skill, no two ratings were alike. There is a method of comparing meter ratings which is a practical test of the accuracy of the work, and is as follows: All the ratings of a meter, when reduced to revolutions of the wheel per second, and velocity in feet per second, and plotted on co-ordinate paper, should give parallel curves. The distance these curves lie apart depends entirely upon the friction of the bearings of the meter wheel at the time the ratings were made. When a meter has been rated so that the curve has been accurately determined, all subsequent ratings should give the same curve or parallel curves, unless the meter has been altered in shape. If the friction of the bearings only has changed, the curves will lie apart from each other, but they will remain parallel. A slight change in the

shape of a meter wheel makes only a very slight change in the curve. Accurate ratings, made by the writer at different places and by different methods, of seven meters of the same size and kind, gave curves which were as nearly parallel as they could be plotted. The distance from the origin at which the rating curve intersects the axes of ordinates represents the friction of the bearings, and by trial in still water the wheel will begin to turn when the meter is moving at a velocity only a trifle greater than the intercept on the axis of ordinates obtained by a careful rating. Mr. Price.

Several ratings of meters on the lower Mississippi, which were reduced on the assumption that a rating could be expressed by the equation $y = ax + b$, have determined b to be a minus quantity. If this result were true, these meters would solve the problem of perpetual motion. Such a result with any meter, or by any method of computation, shows the work of the observer to be inaccurate. Slight changes in the friction of the bearings make but very slight changes in the value of b.

The experience of the writer indicates as untrue the theory that when a meter is cleaned or a bearing oiled the effect is immediately perceptible in the rating. Real variations in the correct rating are caused by serious injury to the meter, or by it being out of order in some way that can be seen easily by a skilful observer; and when it has been properly repaired, the rating will be practically the same as before. It is not subject to constant changes in rate when properly cared for, but these apparent changes are due to a variation of the currents which are allowed to act on the wheel in rating it, and to other errors of observation. Some engineers lack the mechanical skill which is needed to know when the meter is in good order. It is very necessary for the lower bearings of meters like those in use on the lower Mississippi to be in such condition that the current, pressing against the wheel in a direction normal to the shaft, will not cause the wheel to rise in its bearings, as if it does so, the lower air tube is liable to come in contact with the base of the pintle, which will greatly increase the friction. The meter should be tested by pressing the hand against the wheel in the direction normal to the shaft.

The meters which have been most used on the lower Mississippi are so constructed that it is impossible for sand or grit of any kind to get into the bearings, and when they are well cared for the friction is a constant quantity.

Mr. Price. The rating curve of these meters, which are necessarily strong and heavy, departs more from a straight line than the rating curve of the acoustic meter, which is much lighter in construction and has much less friction in its bearings, but the Ellis meter, with a mercury cup contact breaker attached to it, which makes the friction the same as that of the heavy meters, also gives a curve approaching as near to a straight line as that of the acoustic meter. The difference in the curvature of the ratings of different kinds of meters is evidently due to the forms of the wheels, and not to a difference in the friction of the bearings. The method of rating described in *Engineering News* of January 10th, 1895, will enable the observer to secure more accurate data than can be obtained by some methods which have been commonly used. It eliminates some sources of error, and enables a skilful observer to determine the direction of the curve and the intercept very closely.

The curves of vertical velocity for different depths and stages of the Mississippi have not been as accurately determined as they should be. Some of the observations for this purpose have been made with apparatus which could not give accurate results. Those made in 1882 were inaccurate for two reasons at least. The meter had bearings that soon became filled with sand, which changed its rate, and with the apparatus used to suspend the meter in a deep swift current it was impossible to tell at times within several feet at what depth the meter was measuring the current. At Paducah, in 1882, and at Carrollton, in 1883, a better meter was used, and a different apparatus for suspending the meter enabled the observer to locate it very closely at all depths.

At Sioux City in the winter of 1894 the vertical velocity curve in the Mississippi River under the ice was very carefully measured by the writer by a series of observations. The percentage of mean velocity to mid-depth velocity varied, for different parts of the discharge section, from 0.901 to 0.915. The mean of all observations was 0.91.

Mr. Miller. CHARLES H. MILLER, Esq.—Many of the difficulties encountered in observations on the Mississippi are due to the choice of location. The general practice thus far has been to locate the section on a narrow part of the river, a straight reach if possible, but this does not receive as much consideration as the width. Instead, the section should be

located on a wide, straight reach, where the currents are flowing nearly parallel to each other. The narrow river is under abnormal conditions; the water, being forced in at the head of the reach at various angles, causes boils and eddies, and the increase of depth below datum over the shallow section indicates a vertical current, especially when the section is in the upper end of the pool, as at Arkansas City. Mr. Miller.

The main objection to a wide section would be the length of time consumed in taking an observation, permitting the currents to change considerably before the observation could be completed. It is a question, however, whether or not there are any very great changes in such a section. Nevertheless, the trouble could be easily obviated by an increase of force and apparatus; in fact, the ideal condition would be to have a line of current meters extending across the river, all observing at the same time. The time of taking an observation has, in recent years, been reduced fully one-half. The method formerly pursued was to take velocity observations over the entire section first, which required from two to three hours; then the section was sounded to obtain the area. Very often the interval between these observations was as much as three to four hours. The method now used is to measure the section at the same time that the velocities are taken, sounding between stations as the steamer moves from one to another. The time of holding on stations has been lessened, and is usually two minutes instead of from five to fifteen. This reduction has not impaired the accuracy of the work at each individual station, and, taking them collectively, it has reduced the chances for changes in the currents.

Regarding the difficulties of manipulation, a thorough examination of the error due to the drift of the steamer was made during the observations of 1892. The path of the steamer was found by two transits on the shore, taking simultaneous readings every 30 seconds to a pole placed directly above the meter. These points were plotted to a large scale and the required computations made, showing practically no error due to lateral drift, and very little to direct drift, the sum rarely going over ½%, and nearly all of it found on one or two stations. Greater care is now taken that the steamer is on the range at the times of beginning and ending, thus eliminating direct drift also.

A 3-ft. vane on the lower end of the lead-weight holding the vertical rod on which the meter is placed precludes any error due to the meter being forced into any other than a horizontal position, except

Mr. Miller. by the currents themselves. This was determined by fixing in the side of the weight an automatic appliance for measuring the greatest angle of inclination, and was used for depths as great as 60 ft. without finding any appreciable error. It may be mentioned here that this weight is of lead, presenting a wedge-shaped face to the water fore and aft; it weighs 250 lbs., and is lowered with a ¼-in. steel cable from a drum. A guy line of No. 12 wire attached to the top of the rod, on which the weight is fixed, and leading up to the forward end of the steamer, prevents the current from carrying the weight and meter back of a perpendicular. Tests under the above conditions have proved that the meter can be placed within 0.5 ft. of the desired position.

As to the discrepant results shown by the observations at Arkansas City and Wilson's Point for 1891 and 1892, and the near agreement of the results for 1893 at the same places, it is evident from the thorough tests of 1892 that the disagreements were not due to errors of observation. Among other tests, the meters were exchanged, each observer taking the other meter as a new one, rerating it, and applying the rate found to his observations taken with it. Next, the chief observers were changed, each taking the other party and section, and finally the Wilson's Point party and outfit moved to Arkansas City and worked side by side with the other party on that and the Chicot City ranges. Still the results accorded from day to day. The only reasonable solution of the difficulty seems to be the fact that the positions of the ranges for 1893 were changed somewhat from the old locations of 1891 and 1892, in order to get the ranges more nearly perpendicular to the flow, and also at Wilson's Point to escape as much as possible the eddy action on the Mississippi side. In the "Report of the Mississippi River Commission for 1894," it is stated on page 2813, for Arkansas City:

"The old range used for several years past was changed; in azimuth swung down stream 6° 40′, its east end being 560 ft., its west 200 ft., below the old position."

For Wilson's Point, on page 2816, it is said:

"As shown on the map which accompanies this report, the section was moved about 250 ft. below the range used in previous years; first, to try and get below the eddy on the Mississippi side; and, second, in order to have the range just 2 000 ft. below the transit point Δ Ruple. The direction was also changed about 4½°, in order to have it more nearly perpendicular to the flow, as evidenced by the flow across the section last season."

H. ST. L. COPPÉE, M. Am. Soc. C. E.—The vast heterogeneous accu- Mr. Coppée.
mulation of data in the reports of the Mississippi River Commission has remained practically undeveloped or arranged, though explored by many for special purposes. By one who is accustomed or compelled to delve in the several thousands of pages of these volumes, the difficulty of the task undertaken by the author is fully appreciated. The investigation relative to the physical phenomena of the Mississippi River instituted and being carried on by the Mississippi River Commission is an engineering work second in importance to none that has been undertaken during the present century.

It is undoubtedly true that the fundamental laws of hydraulics as applied to rivers or streams are "called into question at the present day," by engineers and authors of reputation. The important facts and laws of physical science have been discovered by experiment or concrete physical evidence, and not by abstract deduction from hypotheses originating in the brain of the mathematician. By this great work of the Commission sufficient data may be obtained in a time not far distant to direct the way, at least, to greater discoveries in the field of hydraulics, and lead to more perfect methods for the improvement of other streams as well as the Mississippi.

As the author states, the difficulty of ascertaining the discharge of a river like the Mississippi is very great. Indeed, it cannot be obtained free from considerable error, owing to the presence of inequalities in the bed and cross-section, and other phenomena causing very irregular flow to which no simple formula will apply and for which no accurate methods of observation can be successfully employed. It is the opinion of the writer that in the endeavor to obtain a large number of fairly accurate data, the quality of the observations is sacrificed for the quantity; for instance, in sounding from a moving steamboat, and also in the small number of soundings taken on a discharge section. The current meter as used by the integration method or run at given depths, checked by flanking, though subject to inaccuracies, is manipulated with greater facility than floats or rods, and unless the latter are used in considerable numbers at short intervals of time, gives better results on the whole. An example of the irregularity of flow of the Mississippi, the change in lateral slope, the obliquity and pulsation of the current, is afforded by observations of the writer at Vicksburg. The river in that locality is approximately as shown in

Mr. Coppée. Fig. 1. During a period of about three years, the writer made careful observations of the depth of water and change in bottom at all stages in the vicinity of the Queen and Crescent Railroad transfer incline at *D* in the figure. These observations disclosed the fact that there was at certain elevations of the water surface, most markedly when the river was at bank-full stage, pulsation in the flow in the neighborhood of this incline. It was first noticed when the water was just over the bank and the only dry spot in the vicinity, consisting of a small mound of cinders dropped from the ash pan of a locomotive, was occupied as an observation station by the instrumentman from which to record the position of the soundings. When first occupied the mound was dry, but in the course of about half an hour the observer was standing in water ankle-deep which receded in about an hour, leaving him on dry ground again. At intervals of about an hour there was a recurrence of the maximum elevation of the water surface, which was found by reading the gauge, located at *B*, to be about 0.3 ft. above the minimum. During the same period the work of dredging the Government canal, shown in the figure, was in progress. At the mouth of the canal, at *A*, a long spar buoy was used by the contractor as an indicator, pointing the direction of the constantly changing currents in the river and serving as a guide to pilots towing scows into the cut. When in slack water the buoy floated in a vertical position; when the cross-current was in the ascendant, an eddy current ran from *B* to *A* and the buoy inclined up stream, the reverse being the case at the culmination of the pulsation.

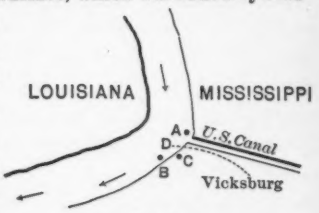

FIG. 1.

The relative values of apparatus and method, of error of observation and error of deduction, are shown very clearly by the author; but to understand fully the impossibility of obtaining an accurate estimate of the discharge of the Mississippi River one must have been in a light skiff on its surface at about the bank-full stage. Then the difficulty of the undertaking and the absurdity of an attempt to apply directly general formulas, or, indeed, any formulas, to obtain accurate results are fully appreciated. That a difference of 100 000 cu. ft. per second is found between discharge-sections seems but natural when

viewing the seething mass of boiling water of this great river at flood stage. Mr. Coppée.

By a careful study of a great mass of data and the construction from it of tables and curves of the elements involved in the evolution of the discharge, the author has established facts that are of the greatest interest and value. The uncertain quantities in the problem vitiate to some extent the value of the deductions, but the results throw light on many mooted questions and give an estimate of future flood heights for a leveed river which will influence the work of protection now in operation and further projects for improvement.

J. B. JOHNSON, M. Am. Soc. C. E.—While the writer has no desire to criticise the paper in any respect for what it contains, he regrets that the author did not continue his studies a little farther, and give his views on some of the vital questions now confronting the Mississippi River Commission, and through it the United States Congress. If he would not care to express his individual opinion on questions as yet unsettled and in a state of controversy by the members of the Mississippi River Commission, he could properly have given some of the accumulated facts on which approximate estimates might be based. Thus by far the most serious and urgent question pertaining to the discharge of the Mississippi River is the determination of the effect of complete confinement by levees on the maximum discharge throughout the entire length of the river below Cairo, and the probable heights the surface would reach throughout this portion of the river if so confined. He has worked out his conclusions as to these two facts for one particular point upon the river, this being Arkansas City. He has done well to take the flood of 1882 as the standard maximum flood discharge, since it was not only the largest on record, but it was more thoroughly and completely studied and measured than any other great flood has ever been.* It was the writer's fortune to study this flood in the field at its height and to measure the discharge from the main channel through the breaks in the levees from Memphis to the mouth of the Red River. Five parties were measuring the discharge of the water in the main channel at as many different points, and three field parties were studying the discharge over the banks, through the levees, and across the swamps. On his return from this trip, he included in his Mr. Johnson.

* See a paper by the writer on "Great Floods on the Lower Mississippi as illustrated in the Flood of 1882," in the *Journal of the Association of Engineering Societies*, Vol. II, p. 115.

Mr. Johnson. report to the Mississippi River Commission, an approximate estimate of the heights this flood would have reached had it been entirely confined to the river channel.* These estimates were so great as not only to be entirely beyond belief on the part of the other engineers connected with the service, but to produce a general chorus of derision, and the charge that his extraordinary personal experiences on this trip had sapped the foundations of his reason. It was not long, however, before the president of the commission himself became convinced that the effect of flood confinement would be to raise the flood stage for such a volume as passed in 1882 to very much the same heights,† although he has continued to stand alone in that body in this matter.

The popular and almost universal opinion has been that the confinement of the entire flood volume to the river channel would cause it to deepen and widen its bed immediately, and to increase its velocity, so that no appreciable increase in flood height would result. It is interesting, therefore, to find the author estimates that the flood stage at Arkansas City for the passing of a volume like that of 1882 through a channel confined by levees would have been 55.8 ft. As the highest stage at that point in 1882 was 47.1 ft., he estimates an increased stage due to flood confinement at that point of 8.7 ft. The writer's estimate for the increased stage at this point made in 1882 was 9 ft. Since all of his estimates were of course merely approximate, not having the necessary data for a complete study of the problem, he regards this as a practical agreement, and desires to have the author's estimates of the corresponding increased stage at the various other portions of the river for the passing of this same flood throughout a confined channel.

More especially is this desirable at this time, since the Mississippi River Commission has now decided by an almost unanimous vote to shut off the Red-Atchafalaya River system entirely from the Mississippi, thus requiring the Mississippi River channel below the mouth of the Red River to carry the entire flood coming down the channel from above that point. As this lower river has never been able to carry more than about 1 200 000 cu. ft. per second, and would be called upon in the case of this closure, with a flood like that of 1882, to carry about 2 000 000 cu. ft. per second, it is of supreme importance to determine

* See the "Report of the Mississippi River Commission for 1884," Appendix A1.

† See the "Report of the Mississippi River Commission for 1883," Minority Rep. of Gen. C. B. Comstock.

what will be the effect on flood heights of the Mississippi River, in the State of Louisiana, when its maximum volume is thus increased by over 60 per cent. The Atchafalaya River is now a legitimate natural outlet for great floods on the lower river, and if the agents of the United States close this outlet against flood water, and force the main channel to carry the entire flood, which it never has done hitherto, does it not necessarily follow that the United States Government may justly be called upon to pay all damages resulting from the overflow of such levees as now exist on this portion of the river, or first raise these levees to such a height as will give the channel a sufficient capacity to carry these increased volumes? It is said that the Commission has decided to close this outlet, but it is not stated that any action had been taken toward raising the heights of the levees in that portion of the river to enable it to carry safely the greatest floods after this closure has been effected. It is well known that some of the members of the Commission are of the opinion that the effect of closing this high-water outlet would be to cause the main river to discharge the increased volume at the same stage, or possibly a lower one, which has accompanied the discharge of previous floods, reduced by the drawing off through this outlet of several hundred thousand cubic feet per second. This is a question, therefore, of immediate and vital importance, and it would be interesting to have the author's views on the matter. While no one would wish to make a very definite prediction as to the effect of any such cause, it would seem that engineering science ought to be competent, and that the data now accumulated by the Mississippi River Commission ought to be sufficient, to enable an approximate estimate to be made of the results of such a step, and of the increase of flood stage for a confined channel from Cairo to New Orleans. Mr. Johnson.

ARTHUR HIDER, M. Am. Soc. C. E.—In 1892 the writer, who has had supervision of the different discharge parties engaged for several years past in what is known as the Third District of the Mississippi River, including the stations at Arkansas City and Wilson's Point, made some tests of the meters used in discharge work, in order to determine if possible whether the large discrepancies between these two stations, 100 miles apart, were due to errors of observations, unreliability of instruments or other causes. The results of these tests are given in the table on page 324; the discharges show large discrepancies. The discharge at Wilson's Point has been moved forward one day for compari- Mr. Hider.

Mr. Hider. son of results, to allow for the time interval of water passing the upper station reaching the lower.

RESULTS OF HIGH-WATER DISCHARGE OBSERVATIONS AT ARKANSAS CITY AND WILSON'S POINT.*

Date. 1892.	Total discharge at Arkansas City. Cubic feet per second.	Date. 1892.	Total discharge at Wilson's Point. Cubic feet per second.	Difference. Cubic feet per second.
April 22	1 310 000	April 23	1 297 000	13 000
23	1 449 000	25	1 321 000	128 000
25	1 385 009	26	1 344 000	41 000
26	1 525 000	27	1 350 000	175 000
27	1 597 000	28	1 392 000	205 000
28	1 524 000	29	1 406 000	118 000
29	1 546 000	30	1 344 000	202 000
30	1 587 000	May 2	1 378 000	209 000
May 2	1 624 000	3	1 406 000	218 000
3	1 532 000	4	1 279 000	253 000
4	1 733 000	5	1 372 000	361 000
5	1 589 000	6	1 337 000	252 000
6	1 648 000	7	1 382 000	266 000
7	1 613 000	9	1 377 000	236 000
8	1 659 000	10	1 425 000	234 000
10	1 601 000	11	1 327 000	274 000
11	1 493 000	13	1 365 000	128 000
13	1 466 000	14	1 301 000	165 000
14	1 409 000	16	1 268 000	141 000

* See the "Report of the Chief Engineer of the United States Army for 1893," pp. 3686-88.

The current meters used, designated as Price Nos. 38 and 39, were new instruments received from the makers but a short time before the parties took the field. Both of the current meters are of improved construction, and an examination of the plotted ratings, taken at different localities at separate times by both chiefs of parties, shows that they kept their ratings practically uniform during nearly the entire time they were in use.

At the close of the work both meters were found to be in good condition, the rating of No. 39 being unchanged, while that of No. 38 had changed but slightly.

Meter No. 38 was used in the earlier observations at Wilson's Point, and No. 39 at Arkansas City; the later observations at Wilson's Point were made with No. 39, and at Arkansas City with No. 38. The meters were exchanged on May 28th, an old meter designated as No. 5 being used at Arkansas City on May 30th, while waiting for meter No. 38 from Wilson's Point; afterward the observers changed stations in order to find out, if possible, whether the difference in results could be

charged to the instruments, to the difference in the method of doing the field work, or to personal errors of the observers. Mr. Hider.

To account for the large differences shown in this table, the first explanation suggested is to charge the disagreement either to errors in field work or to unreliability in the instruments used. As the chiefs of both parties were skilful, careful and experienced observers, and after changing stations and instruments these discrepancies still existed, some other reasons beside errors of observation were sought to account for the wide differences.

Fluctuations of current will no doubt account for a part of the discrepancy in the two sets of observations, but for probably only a small percentage of the large difference in the earlier observations. An examination of the field notes at both stations shows that there is often a great difference in velocity found on the same meter station from day to day as well as from minute to minute, the velocity sometimes varying as much as 20% on many of the stations in two consecutive minutes. This is probably due to a variety of causes, change in direction of filaments of water due to the effect of winds, or eddies and boils caused by uneven shape of bottom, etc. Whatever the cause, the fact remains that great variations and fluctuations in the current do actually exist.

In order to eliminate as far as possible any error from this cause, it has been customary to occupy each station for five consecutive minutes or even longer so as to obtain a mean velocity for that particular station. To further test the discharge at Arkansas City, a new discharge station was selected at Chicot City about 7 miles above Arkansas City. The discharge was measured with different meters three days in succession and by different observers. These results will be noticed hereafter in detail. At the close of the observations at Arkansas City, an experiment was tried at the Chicot City discharge sections to further test the workings of the meters by placing a meter on each side of the steamboat and measuring the discharge at the same time independently by each meter. Simultaneous observations were taken with both meters, the stations being occupied the usual length of time, five minutes. The distance between the meters on opposite sides of the boat was 25 ft., meter No. 38 being placed on the starboard, and meter No. 39 on the port, side. The results obtained are given in the table on the following page.

Mr. Hider.

Number of Station.	Revolutions in Five Minutes.		Mean Velocity. Feet Per Second.	
	Meter No. 39.	Meter No. 38.	Meter No. 39.	Meter No. 38.
14	116	108	1.59	1.71
13	235	234	3.38	3.34
12	328	314	4.43	4.59
11	337	330	4.64	4.72
10	408	380	5.28	5.67
9	405	383	5.32	5.63
8	499	390	5.47	5.79
7	414	415	5.71	5.75
6	407	354	4.95	5.66
5	402	390	5.41	5.59
4	431	475	5.49	5.98
3	479	369	5.14	5.56
2	344	371	4.37	4.81
1	251	235	3.40	3.55
	5 056	4 747	64.58	68.35

The discharge given by meter No. 38 is 1 108 256, and by meter No. 39 is 1 035 156, cu. ft. per second, meter No. 38 giving a discharge 7.06% greater than meter No. 39. The mean of the velocity determined by dividing the sum of the revolutions by the time of the observation in seconds and applying the ratings determined for each meter gives as the mean velocity on the starboard side for meter No. 38, 4 882 ft. per second, and that for meter No. 39 on the port side, 4.613 ft. Meter No. 38 gave a velocity 5.83% greater than meter No. 39 on the opposite side of the boat. It will be noticed that the results obtained by meter No. 38 are always somewhat in excess of those obtained by meter No. 39. This, if the velocity was the same on both sides of the boat, is contrary to what might be expected from stations 14 to 7, as the velocity is continually increasing to that point, so that meter No. 38 on the starboard side should really give a somewhat less velocity than meter No. 39 on the port side; from stations 1 to 7 the velocities decrease, and meter No. 38 should give greater velocities, which it does.

These observations at Chicot City were taken July 2d, when the river was at 44.85 ft. on the Arkansas City gauge, or 5 ft. below high water. The river was falling at the rate of 0.5 ft. in 24 hours, which at this stage is a rapid fall and would tend to produce a considerable shifting and a consequent variability in the current at any one point in the section. This is shown by an examination of the field notes.

Other observations were made August 17th, 1892, by the writer

at Greenville, Miss., after the discharge measurements had been concluded, to further test the workings of these two meters. Mr. Hider.

The meters were placed as before, one on each side of the steamboat, 25 ft. apart. Four stations were occupied for five minutes each, and then the meters changed to opposite sides of the boat, and the observations repeated.

The results are given in the following table:

Meter No. 39 on Starboard Side.		Meter No. 38 on Port Side.	Meter No. 38 on Starboard Side.		Meter No. 39 on Port Side.
	Revolutions.	Revolutions.		Revolutions.	Revolutions.
Station 1.....	26	30.5	Station 1a....	31.5	30
	30	37		26.5	29
	34.5	39		34	35
	33.5	34		30.5	36
	36.5	36		27.5	30
Mean	32.10	35.3		30.0	32.
Mean velocity..	2.370	2.405		2.215	2.285
Station 2.....	37	37	Station 2a....	34	36
	36	32		33	31
	34	35		—	—
	34	39		34	35
	34.5	38		35.5	34
Mean	35.3	36.2		34.125	34.00
Mean velocity..	2.422	2.433		2.360	2.356
Station 3	45	46	Station 3a....	45	46
	49	50		45	45
	48.5	49		48	43
	53.5	53		50	49
				56	54
Mean	48.75	49.5		48.8	47.4
Mean velocity..	2.904	2.865		2.843	2.826
Station 4.....	47	50	Station 4a....	38	37
	46	46		38	35
	44	45		39	36
	41	43		37	43
	41	41		44	40
Mean	43.80	45.00		39.20	38.1
Mean velocity..	2.710	2.725		2.553	2.510

A comparison of the means of these observations shows a remarkably close agreement, and demonstrates the reliability of the instruments and the correctness of the ratings used in the discharge observations.

Mr. Hider.

MEANS.

Station.	Meter No. 39 on Starboard Side. Velocity per second.	Meter No. 38 on Port Side. Velocity per second.	Station.	Meter No. 38 on Starboard Side. Velocity per second	Meter No. 39 on Port Side. Velocity per second.
1.....	2.370	2.405	1a ...	2.215	2 285
2.....	2.422	2.433	2a ...	2.360	2.356
3.....	2.904	2.865	3a ...	2.843	2.826
4.....	2.710	2.725	4a ...	2.533	2.520
Mean.	2.606	2.607	....	2.488	2.488

At the time these observations were taken all conditions were extremely favorable for exact work, no wind, river calm, Greenville gauge 14.5 ft., meter submerged 15 ft., and river nearly stationary. The interval between observations at Stations 1 and 1*a* was about 40 minutes; 2 and 2*a*, 30 minutes; 3 and 3*a*, 20 minutes; 4 and 4*a*, 10 minutes, the boat crossing the river from Station 1 to 4, and, returning, taking the stations in the reverse order. It will be noticed that during this time the velocity on some of the stations varied considerably during the interval between observations.

Another test was made the same day by placing both meters on the same rod, one above the other, and 2 ft. apart; a 60-lb. lead was attached to the bottom of the rod 18 ins. below the lower meter. The

	Meter No. 38 Above. Revolutions.	Meter No. 39 Below. Revolutions.	Meter No. 39 Above. Revolutions.	Meter No. 38 Below. Revolutions.
Station 1.....	28	30	31.5	31
	31	33	31.5	31
	33	34	29.5	30
	33	36	31	32
	32.5	34	29.5	30
Mean....	31.5	33.4	30.3	30.4
Mean velocity....	2.265	2.333	2.220	2.235
Station 2.....	36.5	38	35	35
	39	40	38	38
	35	34	40	40
	33	33	41	44
	35	34	37.5	38
Mean.....	35.3	35.8	38.3	39.0
Mean velocity....	2.404	2.420	2.500	2.538

lower meter was submerged 15 ft., two stations were occupied, and observations at each station lasted five minutes. A copy of the notes is given in the table at bottom of preceding page. Mr. Hider.

It will be observed that the lower meter gave slightly higher velocity. In one case the mean gave an increase of 0.042, and in the other case of 0.027 ft. per second, caused probably by the disturbance in the current due to the obstruction formed by the weight 18 ins. below the lower meter.

A still further test of the working of these two meters was made the same day. The steamboat, with a meter submerged 15 ft. on each side, was run slowly across the river, keeping on range; the revolutions of each of the two meters were counted and recorded each minute. Meter No. 38 was on the starboard side and No. 39 on the port side. The results of the observations were as follows:

No. of Minutes.	Meter No. 39.	Meter No. 38.	No. of Minutes.	Meter No. 39.	Meter No. 38.
1	33	36	15	59	60
2	44½	44	16	67	70
3	53	54	17	54	51
4	58	58	18	52	52
5	64	66	19	49	45
6	66	66	20	41	41
7	68	68	21	32	36
8	69	69			
9	69	69			
10	69	69	Total revolutions	1 196½	1 211
11	68	69	Revolutions per second	.950	.961
12	64	69	Mean velocity	4.055	4.050
13	62	60			
14	59	60			

These observations again show a very close agreement, the difference in mean velocity after 21 minutes of consecutive observations being only 0.1 per cent. The three sets of observations, which were made with extreme care and under very favorable conditions, prove clearly the reliability of the meters used in the discharge observations, and also the correctness of the ratings used in the computations, which were the same as those used in these experiments.

An examination of these results shows that the velocity at any one point in the sections varies to a considerable extent in a short period of time. This being admitted, the variations in the discharge, comparing one day with the next, cannot be fairly charged to irregularity of the meter's action, but much more probably the difference is due to the variability and fluctuations in the velocity of the current itself.

Mr. Hider. There is no reason why an instrument as carefully constructed as one of these current meters should not register the facts, and there is no doubt but that the current meter does register the velocity that actually exists at the time the station is occupied.

Another test of the accuracy of the meter work is given by the result of double-float observations. The lower float was submerged six-tenths of the depth, the same as for meter work, and the observations were taken at both stations; the discharges were also measured by the meters the same day. The results are given in the following table:

Place.	Date.	Cubic Feet per Second.		Percentage of difference between meter and floats.
		Floats.	Meter.	
Arkansas City.....	May 14....	1 407 489	1 395 708	— 0.08
"	" 23....	1 486 551	1 436 379	— 3.37
"	June 20....	1 403 133	1 379 797	— 1.66
"	" 30 ...	1 198 481	1 138 237	— 2.21
"	July 1....	1 182 964	1 138 237	— 3.78
Wilson's Point.....	May 19....	1 245 815	1 273 454	+ 2.22
"	" 27....	1 297 915	1 345 600	+ 3.68
"	" 30....	1 282 161	1 257 200	— 1.94
"	June 6....	1 227 766	1 213 740	— 1.14
Chicot City.....	June 30..	Meter, morning. 1 047 756	Meter, afternoon 1 066 256	+ 1.73
"	July 1....	Floats. 1 064 356	Meter. 1 022 056	— 3.97

The preceding table shows as close agreement with meter work as could be expected, when it is considered that the meter was run in the forenoon, the section sounded and the floats run in the afternoon, some three or four hours intervening between the two sets of observations, the same soundings for determining the area of the section being used to obtain the final discharge with the meter and double floats.

The test at the Chicot City station, 7 miles above Arkansas City, made at the close of the discharge observations, by placing a meter on each side of the boat, shows a wide discrepancy when the discharges at the two stations are compared.

Date.	Arkansas City.		Chicot City.		Difference.
	Meter.	Discharge per second.	Meter.	Discharge per second.	
		Cubic feet.		Cubic feet.	Per cent.
June 28.....	39	1 188 987	38	1 281 656	— 7.79
" 29.....	39	1 179 450	38	1 250 156	— 6.00
" 30.....	38	1 174 778	39	1 047 756	+10.81
July 1.....	38	1 140 517	39	1 022 056	+16.19

Double floats were run at Arkansas City on June 30th. Meter gave 1.73% less than floats. Mr. Hider.

Double floats were run at Arkansas City on July 1st. Meter gave 3.78% less than floats.

Double floats were run at Chicot City on June 30th. Meter gave 1.73% less than floats.

Double floats were run at Chicot City on July 1st. Meter gave 3.94% more than floats.

It would seem that the Arkansas City discharge should be somewhat greater than the discharge of Chicot City during this time, due to the draining of the reservoir between the two stations, as the river was falling at the rate of 0.5 ft. per day during this time.

The field notes of velocities obtained on these four days are given in the following tables:

ARKANSAS CITY.

Station.	METER NO. 39.		METER NO. 38,	
	June 28th.	June 29th.	June 30th.	July 1st.
1	3.274	3.041	3.07	3.00
2	5.228	5.011	5.04	5.12
3	5.622	6.025	5.97	5.35
4	6.142	6.297	6.77	6.23
5	5.964	5.815	6.00	5.78
6	5.599	5.599	5.69	5.30
7	4.923	5.360	5.52	5.36
8	5.054	4.882	5.00	4.98
9	4 337	4.290	4.29	4.23
10	3.944	3.859	3.99	3.96
11	5.691	3.799	3 76	3.55
12	3.274	3.127	3.48	3.07

CHICOT CITY.

Station.	METER NO. 38.		METER NO. 39.		
	June 28th.	June 29th.	June 30th. A. M.	June 30th. P. M.	July 1st.
14	1.97	1.64	1.831	1.927	1.592
13	3.32	3 30	3.111	3.319	2.809
12	4.81	4.54	4.547	4.597	4.416
11	5.91	5.28	4.547	4.880	4.332
10	6.68	6.33	5.062	4.852	4.290
9	6.25	5.82	5.367	4.992	5.463
8	6.09	6.02	5.282	5.437	5.151
7	6.27	6.22	5.166	5.527	5.198
6	6.13	5.87	5.162	4.806	5.139
5	6.44	6.01	5.026	4.992	5.216
4	6.16	6.47	5.255	5.282	5.151
3	6.29	5.97	5.127	5.437	5.023
2	5.34	5.27	4.482	5.139	4.509
1	3.80	3.74	3.551	.....	3.418

Mr. Hider. These observations show that the locus of the maximum velocity at the Arkansas City station during the four days was constant; at Station No. 4, at Chicot City, it moved from June 28th to June 29th, from Station No. 10 to Station No. 4, 1 800 ft.; on June 30th it was at the same point. From the morning to the afternoon of that day it moved from Station No. 4 to Station No. 7, 900 ft., and from the afternoon of June 30th to the morning of July 1st it moved from Station No. 9 to Station No. 7, 600 ft. This shifting of the current and the consequent variation of velocity while taking meter or float observations will account for many seeming discrepancies in the results, for the reason that it takes from three to four hours to make a set of either of these measurements, and during this interval considerable variation in velocity at some of the stations may exist, due to the meter measurements following in the wake of the movement of the point of maximum velocity, or *vice versa*.

That the change in the velocity curve due to the shifting of the currents caused by winds, caving banks, change of direction, etc., and consequent change in local slope is at times a considerable source of error in the results obtained by present methods is shown by an examination of the field notes. Taking the discharge at Chicot City as an example, as the meter was run beginning with Station No. 14 and occupying the stations in regular order until the other side of the river was reached, it is evident that on June 28th and 29th the measurements would follow the movement of maximum velocity, and therefore give results somewhat too large. On June 30th and July 1st the reverse would be the case, the results being too small. As the locus of the maximum velocity on the Arkansas City station remained fixed, the results there would probably be more accurate.

The meter and float observations both show that on June 28th and 29th the Chicot City observations were larger than the Arkansas City observations, and on June 30th and July 1st much smaller.

These meter results are checked by float observations which agree very well. As the meters were changed as well as the observers, and the work checked by the float method, there is no reason to doubt the reliability of the results as given by the instruments, or that they were the actual velocities at the time. It seems evident that the change in locus of maximum velocity and mean velocity due to change in local slope is the cause of a part of the difference in the measurements.

Mr. Hider.

The change in reservoir capacity between the two stations would also have a slight effect, and the form and depth of section would have some influence, but neither of these causes nor all combined are sufficient to account for the discrepancies above referred to. There is probably a considerable loss of water between two stations 100 miles apart, from infiltration through the bottom and sides of the river, which is from 60 to 100 ft. deep and flows through an alluvial bed, due to the filling up of an immense reservoir drained during the preceding low water season: how much this may be is purely a matter of conjecture.

The wide difference between the computed discharges at Arkansas City and Wilson's Point in 1890-91 and 1892 suggested to the writer a possible improvement in the method of measuring the discharge, which is referred to in the paper as the flanking method. This change in method was recommended to C. McD. Townsend, M. Am. Soc. C. E., the engineer officer in charge of the district at the time these tests were made, and, in connection with the former or stationary method, has been in use since. The usual method was to divide the entire width of the river into sections of about 300 ft., ascertaining the velocity in the middle of the section by running a meter for five consecutive minutes, and assuming the average velocity so obtained as the mean velocity of the entire 300 ft.

The change in method may be briefly outlined as follows:

For the Stationary Method.—To divide the cross-section of the river into a greater number of equal parts, twenty-four instead of twelve.

For the Flanking Method.—First, to submerge the meter 15 ft., or if necessary 20 ft., below the surface, so as to be below any disturbance caused by the movement of the boat; second, to start the boat at a slow rate of speed across the river, keeping on the discharge range, noting the registration of the meter, and the time of passage between each division; third, to sound the section during or immediately after the meter observations are taken.

The advantages of these changes are the following:

In the stationary method the accuracy of the work is increased by doubling the number of divisions into which the section of the river is divided, and obtaining a mean velocity of each division.

In the flanking method, the meter can be more easily manipulated at a depth of 15 to 20 ft. than 40 or 50 ft. below the surface.

Mr. Hider. Three or four discharges can be measured the same day if necessary.

By noting the time and registrations between each division and making the proper correction for lateral motion of the boat and depth of submersion of the meter, a nearer approximation to the true results will be obtained than by the usual method of assuming that the average velocity taken in the middle of a 300-ft. section in the river will give a mean velocity for the entire 300 ft., as the field notes show that the current is extremely variable and continually shifting. Another advantage is that the usual time of taking the meter observations by the stationary method is from two and a half to three and a half hours, while by the flanking method a complete set of observations across the river and back does not occupy more than one-third of the time, allowing two sets of measurements to be made the same day.

The true velocity can be readily deduced by the simple formula $v = \sqrt{v' - v''}$, where v is the true velocity, v' is the velocity in feet per second as given by the meter between stations, and v'' is the velocity of movement of the boat across the range between stations.

By the stationary method it is assumed that the average velocity of a filament of water from 900 to 1 800 ft. in length passing through a section of the river 150 to 300 ft. wide represents the mean velocity of the water flowing through that section.

By the flanking method there is obtained an integration of all the different velocities of the filaments of water flowing through the section at a uniform depth below the surface. Applying the proper correction for the motion of the boat and for depth of immersion should theoretically give more accurate results than the stationary method.

Assuming that the velocities and directions of flow through the section during the time interval, generally a little less than an hour, remain constant while the observation is being taken from one side of the river and back, in crossing the river in the same direction as the lateral flow, the meter, after the proper correction is made for the motion of the boat, would register the normal flow through the section, less the decrease of discharge due to the lateral movement of the water. Returning across the river against the direction of the lateral flow, the meter would register the normal flow plus the increment due to the lateral movement of the water. It is immaterial whether all the filaments of the water are inclined in the same direction or not, it

DISCHARGES AS DETERMINED BY STATIONARY AND FLANKING METHODS.

Location.	Date.	Gauge.	Discharge, Flanking Method.			Discharge, ordinary method.	Remarks.
			R. to L. Bank.	L. to R. Bank.	Mean.		
Arkansas City	July 8th, 1895	13.5	295 379	270 890	283 135		River raising rapidly.
"	" "	13.9				302 493	
"	Aug. 12th, 1895	18.3	371 730	333 125	352 428		River falling rapidly.
"	" "	17.9				353 531	
"	Oct. 12th, 1895	— 1.2	130 795	74 383	102 589		River falling slowly.
"	" "	— 1.24				120 911	
Wilson's Point	July 24th, 1895	13.9	379 531	367 266	373 399		River falling rapidly.
"	" "	13.8				370 011	
"	Oct. 21st, 1895	— 2.3	104 091	91 717	97 906		River falling slowly.
"	" "	— 2.3				102 054	
Warrenton	Aug. 2d, 1895	13.86	274 302	356 105	315 204		River stationary.
"	" 3d, 1895	13.86				361 641	
"	Oct. 26th, 1895	— 3.73	85 959	108 103	97 031		River falling very slowly.
"	" 26th, 1895	— 3.76				101 657	
"	" 28th, 1895	— 3.90	86 967	109 663	98 315		River falling very slowly.

Mr. Hilder. is seldom that the direction of the current in reference to the discharge range is relatively the same on both sides of the river during high water.

The normal discharge at right angles to the section would be the mean of the measurements taken across the river and back again, and the excess of lateral flow in one direction one-half their difference.

A few observations recently taken by both the stationary and flanking methods at stations about 100 miles apart when the disturbing elements, boils, eddies, irregularity of flow, etc., to which the river is

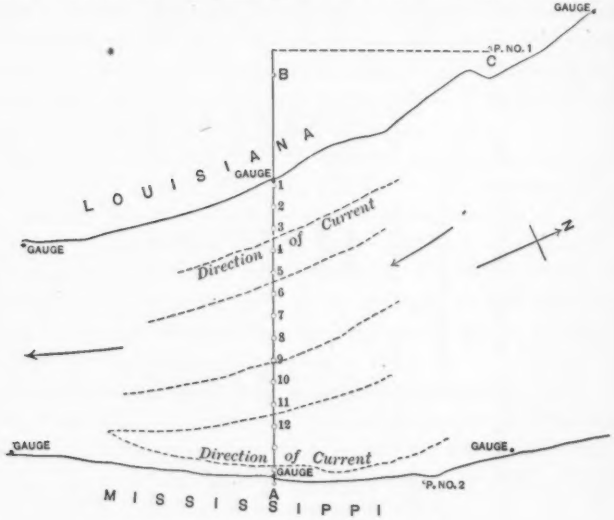

FIG. 2.

subject at high water were at their minimum, are given in the table on the preceding page.

The reason of the wide discrepancies in results between the two methods at the Warrenton station can be seen by an inspection of Fig. 2, showing the direction of the current relative to the discharge range. The importance of taking this lateral flow into consideration in all discharge measurements is evident.

Mr. Townsend. C. McD. TOWNSEND, M. Am. Soc. C. E.—The author's deductions as to the heights to which the Mississippi River may rise when confined are full of vital importance to those interested in levee matters,

but it is believed he has rendered a still more valuable service to the engineering profession as a whole by gracefully removing the mask from that venerable formula $v = c\sqrt{rs}$. When it is shown that the flow of water in rivers fulfils none of the conditions on which the formula is based, the cross-section not being uniform, the velocity constant nor the filaments of water flowing in parallel paths, it is not surprising that difficulty is experienced in its application. The author, however, makes a much more serious attack when he demonstrates that on any section the velocity may not bear a direct relation to the hydraulic mean depth, but an inverse relation, and that the local slopes may not bear the relation to v that the formula indicates. Mathematics is but a process of reasoning, and, starting with false premises, cannot lead to proper conclusions. The author appears to think there is an opportunity to convert falsehood into truth by multiplying by a variable, and the question arises as to what is the value of the quantity that will convert the square root of the product of the hydraulic mean depth of an accidental section and an imaginary slope called a mean slope into another imaginary quantity called mean velocity. It is shown that the location and form of the discharge section bear an important relation to this value. An inspection of the formula shows that c can be made to vary between zero and infinity on most rivers by varying the location of the discharge section, selecting the edge of a fall in one case near the river's source, and in the other a section near the mouth under tidal influence when the slope happens to be negative. The value of c depends on the relation that the discharge section bears to a mean river section and local slopes to mean slopes; in other words, on the fallacies that enter the original premises. The necessity for the author's caution in applying the formula is therefore evident. Every variety of falsehood changes the value of c, and it therefore results that c varies with the section, with the stage, with the slope, and with various accidental conditions. When the author constructs an imaginary river where $v = c\sqrt{rs}$ represents a true relation, the value of c becomes determinate.

Mr. Townsend

An apt illustration of the above thought is given in the paper.* The measurements of discharge in 1893 at Bachelor's Bend and Warfield's Point were taken to determine what influence, if any, the location of the discharge section has on discharge measurements. The

* See *Transactions*, Vol. xxxiv, p. 401.

Mr. Townsend. section at Bachelor's Bend was located in a sharp curve, and the section at Warfield's Point on the crossing below it; the large error found at the former locality simply indicates that the section selected differs widely from the mean river section, and the local slopes from mean slopes, proving that the section was a good one for the purpose intended, but very poor for obtaining correct discharges.

Text books offer excellent advice to select a location for a discharge section in a straight reach of uniform cross-section where the filaments of water are flowing in parallel lines. If this advice could be followed, not only could accurate discharges be obtained, but the author's troubles with the formula $v = c\sqrt{rs}$ would disappear. The whole trouble arises becauses the Mississippi is not that variety of a river; straight reaches are few, uniformity of cross-section is an iridescent dream, the threads of flow are most complicated skeins. In obtaining high-water discharges, it is essential to select a location where the flow of water is unobstructed by trees and undergrowth, as the determination of discharges under such conditions cannot be accurate. In the upper portions of the river this limits the discharge stations to a few localities. The discharge must, therefore, be measured where opportunities occur, not where theoretical considerations would indicate it was most desirable, and to the necessarily faulty location of the discharge section the writer attributes many of the observed discrepancies in discharge measurements. The fact that there was a deflection in the threads of current at Arkansas City of 10° 30′ was not the controlling feature in the process of reasoning given by the author,* but that the floats followed paths which were approximately arcs of circles concave to the Mississippi bank, with radii of curvature of between 6 000 and 7 000 ft., that there was a marked difference in the water level on the two banks of the river, and that the local slopes on the Arkansas side were very gentle, and on the Mississippi side very steep.

If the tendency of water under the action of a centrifugal force is to move in spiral paths, the conditions at Arkansas City are favorable to the development of such action. At Wilson's Point, on the contrary, though some of the filaments of water follow curved paths, some are concave to the Mississippi shore and some to the Louisiana shore, a condition not favorable to the development of centrifugal force.

A direction-current meter will not solve the difficulties which arise in

* See *Transactions*, Vol. xxxiv, p. 373.

such a case. It may give the direction and intensity of a resultant force, but neither the intensity nor direction of the components into which it must be divided will be known. In a pipe or canal the determination of the cross-section is simple, but it is far from being the case in a river. It has been customary to select a section approximately at right angles to the direction of the current, and if the filaments of water move in right lines, the projection of those lines on planes perpendicular to the discharge section gives a correction to the velocity that enables discharge measurements to be made accurately, but if the spiral motion of the water be admitted, then not only is the resultant velocity greater than the true velocity with which the water is running down the river, but the area of the section selected varies from that of the proper section by an amount dependent upon the inclination of the spiral. The multiplication of these two quantities together may lead to large errors. This fact, however, does not materially affect the author's deductions. It is possible that an unknown quantity x may be a better expression than cubic feet per second for the unit, on which his numerical relations depend. The same discharge curve, however, will be obtained if x's of the same value are compared. The analysis to which the discharge measurements are subjected tends to produce such a result. It may be that the discharge observations rejected at Wilson's Point as too small may give the most accurate discharge in cubic feet per second, but they are properly rejected when an investigation indicates that they are not based on the same x that is the unit for the Arkansas City discharges. Mr. Townsend.

The author's deductions of the height that the confined river will attain reopens a subject which has been discussed in the Mississippi valley since the days of Humphreys and Abbott. Two schools of engineers have arisen, one, of which the author by the publication of his paper becomes an able exponent, maintaining that the height that floods will ultimately attain in a leveed river can be mathematically determined; the other, that the influence of the confined river in enlarging the river channel will vitiate any mathematical deduction. With one school, the author's arguments will appear conclusive; with the other, the essential item will be found in the statement* that "the section at Arkansas City, with all its temporary mutations, remains the same."

*See *Transactions*, Vol. xxxiv, p. 489.

Mr. Townsend. The levees have now been constructed to such dimensions that if they are capable of producing any effect on the river channel, there should be evidences of the fact, and it is the writer's purpose to sum up the evidence that exists of the enlargement of cross-section that has accompanied levee construction, and to discuss the effects which enlargement of section will produce on flood heights. This discussion leads to a deduction of levee grades by a process of reasoning entirely independent of that pursued in the paper. For those engineers who have not been heretofore interested in levee construction to understand the discussion some information is necessary concerning the work which has been done on the Mississippi River in recent years. It is proposed, therefore, to preface the discussion by a description as brief as practicable of the levees of the Mississippi River.

TABLE A.—CUBIC YARDS IN LEVEES.

DISTRICT.	LENGTH IN MILES.		CUBIC YARDS IN LEVEES.	
	River.	Levee line.	1882.	1895.
Lower St. Francis	223	118	.....	3 637 083
Upper White	34	32	.....	2 103 132
Lower White	45	33.5	.....	2 108 710
Upper Yazoo	120	123.9	2 600 000	10 434 395
Lower Yazoo	210	190	5 968 726	19 700 000
Upper Tensas	118	*90.8	1 788 300	9 340 917
Middle Tensas	88	87.4	3 181 000	9 357 861
Lower Tensas	155	121.6	5 289 000	10 906 816
Atchafalaya	123	*104	5 043 784	12 295 714
La Fourche	71	*71.3	2 735 284	5 592 863
Barataria	58	60	501 860	1 736 870
Pontchartrain	123	125.8	4 264 638	9 637 297
Lake Borgne	58	60	1 367 680	2 096 549

* Length on Mississippi River.

Prior to the war between the States, the fronts of the different basins were covered by lines of levees, though of weak profile and insufficient height. During the war the contending armies frequently cut the lines, and the floods of 1862 and 1865 very generally destroyed what the troops left. Spasmodic efforts were afterward made by local authorities to repair their levees, but the flood of 1882 again devastated the entire valley. At this period the United States Government offered assistance in reconstructing the levee line, and since that date the work has been vigorously prosecuted by the general government and by State and local authorities. In Table A are given the cubic yards in the levee lines of the various districts after the

flood of 1882, and on June 30th, 1895, and the total length by river of the different districts. Fig. 3 shows cross-sections of levees such as existed in the Upper Tensas District, in which Arkansas City is situated, in 1882, and such as will be found throughout the district before the flood of 1896, when the work now under contract will be completed. The section of 1882 has been determined by dividing the contents of the levee line that then existed by its length. The broken and dotted line of the diagram shows a section to restrain a flood of the dimensions indicated in the paper, with an allowance of 1½ ft. for wave-action. It may be noticed from this diagram that the forms adopted for the levee section differ materially from those which obtain in reservoir construction. The causes of this difference arise from the impracticability of finding in an alluvial valley the foundation impervious to water that is an essential condition in reservoir construction. The material for constructing the puddled core is also not readily obtainable, and its value is not so evident when it can be readily flanked by water passing through a permeable foundation into the embankment beyond. Mr. Townsend.

The essential condition of levee construction is a mound of earth of sufficient height so that water cannot flow over its top; of sufficient mass, so that surfaces of saturation cannot be formed through it on which the superincumbent material will slide; of sufficient width of base, so that the water flowing through the permeable foundation will not have sufficient force to remove any material, it being assumed that the earth has been placed with care, so that there are no channels left across the embankment through which the water can directly flow. This mound of earth must be protected from the eroding action of rains, and its river surface from erosion by river currents and waves during floods. The grade must be somewhat higher than the highest flood to afford protection against wave action during storms.

With the extreme variations in permeability which are found in the soils of which levees are constructed, variations in form become necessary, but practical experience with the soils of the Mississippi bottoms has developed certain forms which are of general application. A slope of 1 on 3, when well sodded with Bermuda grass, has been found to resist the action of rain, of river currents and of minor waves. In localities exposed to the full force of waves through long reaches of

Mr. Townsend.

the river, it is necessary either to reinforce the sod with some more permanent form of revetment, or to adopt a gentler slope.

A width of crown varying from 6 to 10 ft. generally exists. The width to be given to the crown is interdependent with the slope to be given the land side of the levee. An 8-ft. crown affords convenient space for patrolling the levee line during floods, and storing such material as may be required to repair any damage which may be inflicted by storms. With a width of crown of 8 ft., a land slope of 1 on 2 can be safely employed until the levee attains a height of 6 ft.; with higher levees, unless the soil is especially adapted to levee construction, there is a tendency to form surfaces of saturation through the mass on which the upper portion is liable to slide. Levees not exceeding 12 or 14 ft. require a land slope of 1 on 3; above these

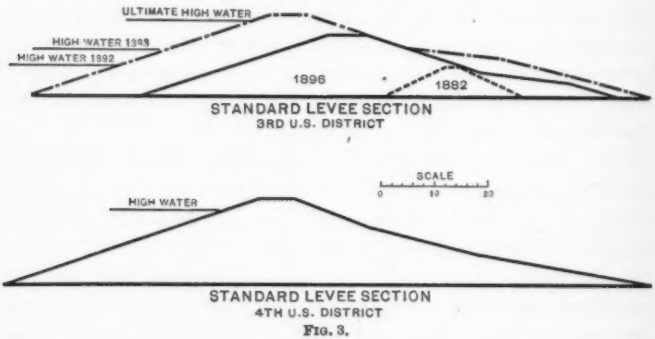

FIG. 3.

heights in the upper basins of the river, trouble begins to be experienced with the foundation, and still gentler slopes are necessary, or the same results may be attained by adding to the base a mound of earth termed a banquette. These banquettes have been built of various dimensions and slopes, varying from 10 to 40 ft. in width, their crests from 6 to 10 ft. from crown of levee, with land slopes from 1 on 3 to 1 on 5, and with top slopes from 1 on 40 to 1 on 10.

In the Fourth United States District, recognizing these principles, a form of section shown in Fig. 3 has been employed. The width of crown is 8 ft., river slope 1 on 3, the land slope for a vertical distance of 6 ft. from the crown is 1 on $2\frac{1}{2}$, for the next 6 ft., 1 on 4; below this, 1 on 6. The objection to this form is that it does not lend itself readily to levee enlargement. Owing to lack

of funds in nearly all the districts it has been impracticable to build levees of the dimensions it is recognized they must ultimately attain. The hope is entertained that several years will elapse before a great flood will occur, and safety is sought against the minor rises which are sure to happen. A weak section is first adopted, which is afterward enlarged as it exhibits signs of failing, and more money becomes available. A trapezoid with the width of the crown adjusted to the financial conditions of districts, and slopes of 1 on 3, is well adapted to this method of treatment. If its base shows signs of failing, it can be strengthened by a banquette even during a flood, and it can be readily enlarged on the river side without destroying the sod on the other slope. The section shown in Fig. 3 must be enlarged on the land side or the slopes readjusted. While these levee sections have resulted from practical experience rather than from theoretical considerations, it may be noted that the sections most generally employed in recent years insure an angle of repose of dry earth on wet clay of 14° when water is at the top of the levee, the limiting angle for such materials. When compared with European practice, it will be found that European levees have in general a greater width of crown and steeper land slopes than are found in Mississippi levees, but about the same width of base.* Mr. Townsend

The engineers engaged in levee construction have heretofore adopted what has aptly been termed provisional grades for their levees. The impossibility of restraining great floods with the money available was early recognized in the various districts, and grades were adjusted to their financial requirements. In 1882 the gaps in the levee line were closed to the height of the flood of 1882. As more money became available, levees were built to a grade 3 ft. above the flood of 1882. In recent years the following provisional grades have been adopted: In the Third United States District and by Louisiana authorities, 3 ft. above the highest flood; in the Fourth United States District, 2½ ft. above the highest flood, and in the Upper Yazoo District, 4 ft. above the flood of 1890; in the Lower Yazoo District, 4 ft. above the flood of 1891; in the St. Francis District, 3 ft. above the flood of 1882. The grades adopted by the Lower Yazoo and Third United States Districts are nearly equal to the United States grade, being a little higher than the local grade at the upper end of the district and a little lower at the lower

*See paper entitled, "Some Notes on the Holland Dikes," *Transactions*, Vol. xxvi, p. 559.

Mr. Townsend. end. They are both about 1 ft. below the grade of the Upper Yazoo District.

By March 1st, 1896, it is anticipated that the levees constructed in these districts will be generally brought to standard section and to provisional grade, and in a number of districts higher grades than those specified have recently been adopted.

While the levees are in an incomplete condition their influence on the high-water discharge of the Mississippi River is already perceptible. In the following table are given the maximum measured discharges in the river channel, and the estimated discharge across the alluvial valley at the latitude of Lake Providence in 1882 and from 1890 to 1893:

Date.	Measured discharge.	Estimated flow across the valley.
1882	1 057 000	2 000 000
1890	1 288 000	1 720 000
1891	1 346 000	1 400 000
1892	1 430 000	1 760 000
1893	1 498 000	1 750 000

This table is derived from the reports of the Mississippi River Commission, and has not been submitted to the rigid analysis that characterizes the paper. The results are, however, given as reported, as they have been used as arguments for solving the question of ultimate flood heights. The discharges at the latitude of Lake Providence are the roughest approximations, as explained in the paper. The increased river discharge has been accompanied at Lake Providence by an increase of 3½ ft. in flood heights. In Table B are given the flood heights since 1872 at the principal gauge stations on the river from Helena to the mouth of the Red River.

While no great flood has been entirely restrained, the gradual increase in the area of land protected from overflow is as marked as the increase in flood heights. During the floods of 1882, 1883 and 1884 the valley of the Mississippi River was generally overflowed, but in 1890 between 80 and 85% of the Yazoo Basin was protected. In 1891 the amount of land overflowed in this basin was still less, and in 1892 and 1893 the levees afforded it complete protection. The Arkansas districts have been generally overflowed during every flood, though in the Upper Tensas District the levee line was successfully maintained in 1891.

Below the Red River in 1890, on the right bank, a continuous line of 180 miles was maintained, and on the left bank there were 200 miles with but one break. In 1891, two crevasses occurred—one, the Ames crevasse, overflowed a territory of about 2 000 square miles; the second, the Fernsley crevasse, occurred as the river was falling; it attained a width of but 97 ft., was readily closed and inflicted only local injury. In 1892 there was but one crevasse in the Mississippi levees of the Atchafalaya Basin. In 1893 no crevasses occurred in the Atchafalaya nor in the La Fourche Basin above New Orleans. Mr. Townsend.

A summary of the evidence of enlargement of section accompanying levee construction will now be given. If the discharge observations

TABLE B.—Flood Heights Since 1872.

Year.	Cairo.	Helena.	White River.	Arkansas City.	Lake Providence.	Vicksburg.	Natchez.	Red River.
1872....	39.2	39.0	40.2	....	35.1	39.5	39.8	39 4
1873....	41.5	40.0	42.9	....	36.1	40.6	40.1	39.0
1874....	47.4	45.8	....	....	37.4	45.7	45.6	47.0
1875....	43.7	42.4	45.0	....	37.3	43.0	41.8	40 4
1876....	46.4	44.8	46.7	....	37.9	44.9	43.8	45.4
1877....	40.5	41.8	44.6	....	35.8	41.6	40.7	40.5
1878....	37.0	38.7	....	....	35.8	40.9	39.2	....
1879....	36.5	37.2	....	....	36.0	39.4	36.8	35.9
1880....	44.6	43.7	46.5	45.1	38.0	43.1	43.5	44.0
1881....	45.2	43.7	45.7	44.3	36.2	41.8	40.8	40.1
1882....	51.9	47.2	48.4	47.1	38.3	48.7	47.7	48.5
1883....	52.2	46.9	48.0	46.3	36.5	43.8	44.0	45 2
1884....	51.8	47.0	47.9	46.5	38.4	49	47.4	47.3
1885....	39	40.7	43.6	42.6	35.5	42.4	42.6	41.9
1886....	51	48.1	48.2	46.9	37.9	44.1	43.7	41.9
1887....	48.5	46.4	47.7	46.8	38	44.7	44.2	43
1888....	45.4	42.8	45.5	45.4	38.1	44.2	43.4	41.7
1889....	35 4	34.1	37.6	36.2	29.4	34.4	34.1	34
1890....	48.8	47.7	50 4	49.5	41	49	48.6	48.6
1891....	46.2	44.7	47 7	48.2	41	48.3	46.5	45.5
1892....	48.2	45.7	49.3	50	41.9	48.4	48	48.8
1893....	49.3	47.9	49.5	50.3	41 8	48.3	46.8	47.7

quoted by the author are examined, it will be seen that while the discharge section at Arkansas City in 1893 has about the same area as in 1884–85, there was an increase in area from 1890 to 1893 which compensates for a reduction in area from 1885 to 1890. During 1890, 1891, 1892 and 1893 great floods occurred, also in 1882, 1883 and 1884, while from 1885 to 1889 the waters of the river were relatively lower, notably in 1889. Colonel Suter has informed the writer that from surveys made near Arkansas City in 1879 at about 11 and 33 ft. on the Arkansas City gauge, the area of cross-section of the river in this vicinity in 1879 corresponded closely to that which is shown by Mr. Starling in 1889, and that in both cases these areas were less than are shown by the

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observations of 1885 and 1893. The year 1874 was a great flood year corresponding to 1884, and was also followed by a similar period of comparatively low water. This would indicate that at this locality during large flood years there is an enlargement of channel section, followed by a diminution of section during low-water years.

Annual surveys have been made of Lake Providence Reach during low water. The mean results of these surveys are graphically represented in the "Report of the Mississippi River Commission for 1892." The low-water areas appear to have followed a similar law to that of the area of cross-section at Arkansas City. A large increase in recent years in the width of river at bank-full stage is also to be noted. At the same stage, the discharge at Wilson's Point appears to have increased since 1890. Professor Whiting, by comparing recent surveys with the records of the Coast and Geodetic Survey, shows that there has been a perceptible enlargement of the river in recent years at New Orleans. Such evidence is not conclusive of a general law applying to the whole river. What may be termed accidental (unknown) conditions may have especially influenced these few localities. The entire river from the mouth of the Arkansas River to Vicksburg has recently been resurveyed, but the results have not yet been published. An examination has, therefore, been made of the relations which exist between the gauges which have been established at various localities.

An investigation made of all low-water readings from 1872 to 1892 of the gauges at Cairo, Helena, mouth of White River, Lake Providence and Vicksburg will be found tabulated in the "Report of the Mississippi River Commission for 1894," page 2971. That table shows a general tendency of the Helena gauge to relatively lower reading since 1882 than previously existed, when comparison is made with the Cairo gauge. The same is to be noticed at Vicksburg. At White River, on the other hand, there was a tendency to higher readings relatively to Cairo in recent years, while at Lake Providence there was first a rise in gauge readings, followed by a fall. During the low water of 1894 the gauges at Helena and White River bore the same relation to each other as existed since 1887. The great change in slope which accompanied this low water occurred between Cairo and Helena.

The gauges which have been established on the Mississippi River are very delicate indices of any change in its regimen, but the height which is recorded on a gauge is affected, not only by changes of area

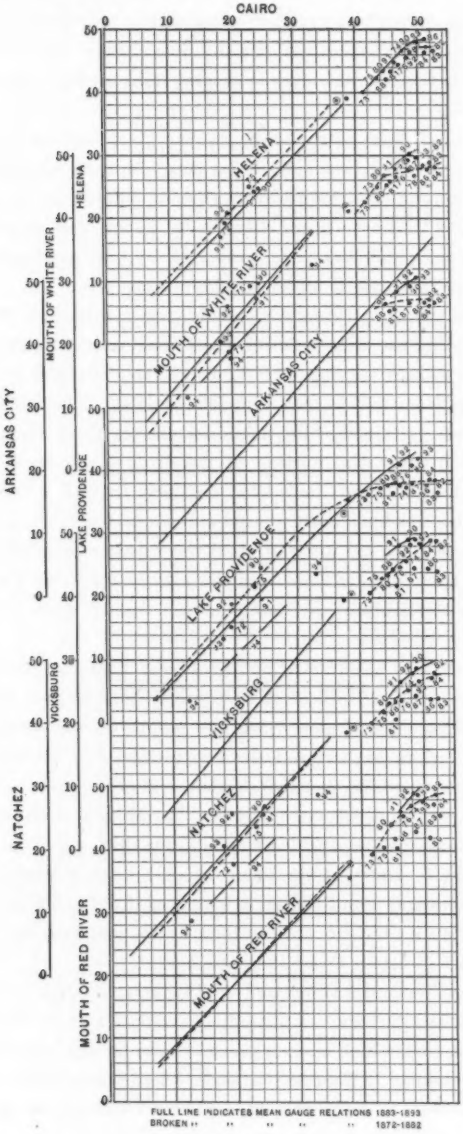
CAIRO
HELENA
MOUTH OF WHITE RIVER
ARKANSAS CITY
LAKE PROVIDENCE
VICKSBURG
NATCHEZ
MOUTH OF RED RIVER
FULL LINE INDICATES MEAN GAUGE RELATIONS 1883-1893
BROKEN " " " " 1872-1882

FIG. 4.

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of cross-section, but by any other cause which influences slope, such as the inflow of tributaries, the rate the river rises or falls, whether the observation is taken as the river is passing from a high to a low stage, or the reverse.

If there has been any change in the river section since levee construction has been resumed, the means of gauge heights for long periods before and after 1882 should show a difference; though large variations may be due to other changes in slopes, the means should show a residual which has been produced by the permanent causes acting during the periods under consideration.

Acting on this hypothesis, the heights on the gauges which have been attained by the crests of rises which have passed Cairo have been tabulated in groups varying by 5 ft., from 5 to 35 ft., and divided into two sections, from 1872 to 1882, and 1883 to 1893. The heights which these rises have attained at the principal gauges from Helena to the mouth of Red River, the portion of the river where levee construction has been most active, have been similarly treated. The means of the various groups have been plotted and connected by lines shown in Fig. 4. These lines do not represent the true gauge relations which exist at any time between Cairo and the gauges mentioned, but means about which the readings oscillate, and are termed mean gauge relations.

The results may be summed up as follows: That the crest of a rise which passes Cairo at 10 ft. on the gauge will tend to pass Helena 2 ft. lower since 1882 than formerly. At the mouth of the White River it will tend to be 1 ft. higher; at Lake Providence, 1 ft. lower; at Vicksburg, 3 ft. lower; at Natchez, 1 ft. higher, and at the mouth of the Red River will have about the same height. The crest of a rise of 30 ft. at Cairo now passes Helena at least 2 ft. lower than prior to 1882, the mouth of White River at the same height; Lake Providence, 3 ft. lower; Vicksburg at about the same height as it did in 1872, and about 2 ft. lower than it did from 1876 to 1880; at Natchez and the mouth of Red River it will attain about the same height.

The gauge relations submitted for Vicksburg prior to 1882 are, however, not satisfactory. A cut-off occurred in 1876 at Delta Point, opposite that city, which made a great change in the regimen of the river in the vicinity. The crests of rises which passed Vicksburg from 1872 to 1876 are too few for a good average, but appear to indicate

TABLE C.—NUMBER OF DAYS IN THE YEAR IN WHICH THE RIVER IS AT VARIOUS HEIGHTS.

Year.	CAIRO GAUGE.						LITTLE ROCK GAUGE.						JACKSONPORT GAUGE.					
	0–10 ft.	10–20 ft.	20–30 ft.	30–50 ft.	40–50 ft.	50–60 ft.	0–6 ft.	6–12 ft.	12–18 ft.	18–24 ft.	24–30 ft.	30–36 ft.	0–6 ft.	6–12 ft.	12–18 ft.	18–24 ft.	24–30 ft.	30–36 ft.
1872..	158	136	54	18	..	..	242	71	26	17	9	..	295	42	19	10	..	..
1873..	95	78	104	74	14	..	224	109	22	10	..	..	247	41	34	31	11	1
1874..	117	116	33	54	45	..	226	77	46	16	..	..	229	33	29	35	34	4
1875..	40	128	83	54	50	..	224	99	38	8	..	..	208	86	37	29	5	..
1876..	44	95	69	97	61	..	178	118	36	24	10	..	155	69	53	42	42	5
1877..	88	108	89	82	3	..	171	98	69	17	10	..	270	31	29	26	9	..
1878..	73	80	160	52	..	..	..	..	..	..	..	..	..	..	..	..	..	..
1879..	69	167	71	58	..	..	315	42	8	..	..	..	309	54	2	..	..	..
1880..	66	89	84	87	40	..	296	53	17	..	..	..	230	44	46	35	11	..
1881..	56	66	116	87	40	..	187	138	39	1	..	..	121	184	26	25	9	..
1882..	50	89	28	93	96	9	116	163	63	16	13	..	152	94	56	39	18	6
1883..	51	87	100	77	36	14	4	245	49	26	11	..	53	120	94	66	27	5
1884..	42	118	92	57	44	13	47	214	71	19	12	3	189	78	46	29	18	6
1885..	7	137	161	60	..	..	83	118	109	41	14	..	200	116	22	15	9	3
1886..	98	61	130	50	18	8	166	167	32	..	..	..	269	39	25	31	1	..
1887..	161	80	52	28	44	..	228	124	13	..	..	..	288	41	19	13	4	..
1888..	27	113	178	30	18	..	132	176	46	15	..	..	252	64	43	11	5	..
1889..	59	108	180	18	..	..	44	220	82	21	..	..	259	96	3	7	..	..
1890..	18	135	80	62	70	..	34	146	131	48	6	..	94	68	47	61	87	8
1891..	73	123	72	31	66	..	76	156	109	24	..	..	169	84	81	31	..	..
1892..	104	61	73	62	66	..	..	230	75	38	18	5	163	102	35	39	25	2
1893..	145	64	50	45	61	..	86	179	71	23	6	..	211	42	55	32	21	4
1894..	151	92	98	24	..	..	173	115	50	22	3	..	209	43	39	34	30	..

Average below 6 ft., Little Rock gauge, 1872 to 1882, 213.
Average below 6 ft., Little Rock gauge, 1883 to 1894, 75.
Average above 18 ft., Little Rock gauge, 1872 to 1882, 13.
Average above 18 ft., Little Rock gauge, 1883 to 1894, 27.

Average below 6 ft., Jacksonport gauge, 1872 to 1882, 22.2.
Average below 6 ft., Jacksonport gauge, 1883 to 1894, 19.7.
Average above 18 ft., Jacksonport gauge, 1872 to 1882, 42.0.
Average above 18 ft., Jacksonport gauge, 1883 to 1894, 52.0.

Mr. Townsend. some such gauge relation as above stated. When the cut-off occurred there was an abrupt change in gauge relations, such as would have occurred if the gauge had been moved up the river several miles, but retaining its zero line at the same elevation above the Gulf.

Before coming to the conclusion that these variations in gauge relations have resulted from changes in sectional area, it is advisable to investigate the other causes which can influence slope. The first to present itself to the mind is the in-flow of a tributary stream. Table C gives the number of days yearly that the Mississippi at Cairo, the Arkansas at Little Rock, and the White River at Jacksonport, have recorded the different heights stated in the headings. It will be seen from the table on the preceding page that in recent years there has been a large increase in the discharge of the Arkansas River, and a perceptible increase in the flow of the White River.

While this increase in the discharge of tributaries might account for the rise of plane at White River, it cannot account for the lowering of the plane at Lake Providence. A perturbation produced by the discharge of a tributary is regularly propagated from gauge to gauge, but could not cause one gauge to record a reading higher than the normal, and the next a lower reading, unless it exerted some influence on the river section.

The extreme low-water readings which are found at the different gauges in 1894, a year in which the river did not exceed a bank-full stage, would indicate that the lowering of gauge relations might be a low-water phenomenon with which levees had nothing to do. The years 1890 to 1894 afford an excellent opportunity to test this theory. At Lake Providence from 1890 to 1894 the gauge annually attained heights differing by about a foot, and though the table at Cairo would indicate little difference in the period the river was above the overflow stage, due to the influence of the Arkansas and White Rivers, the length of time the river at flood stage was exerting an influence at Lake Providence was greatest in 1890, then follow 1892, 1891, 1893, and last 1894, when there was no flood. The length of time the river was at a low stage at Lake Providence during these years is the reverse, 1890 being the shortest period, and 1894 the longest. On the curves of mean gauge relations at Lake Providence and at the mouth of the White River are plotted, in Fig. 4, the actual relations that existed during these years while the river was passing from a low to a high

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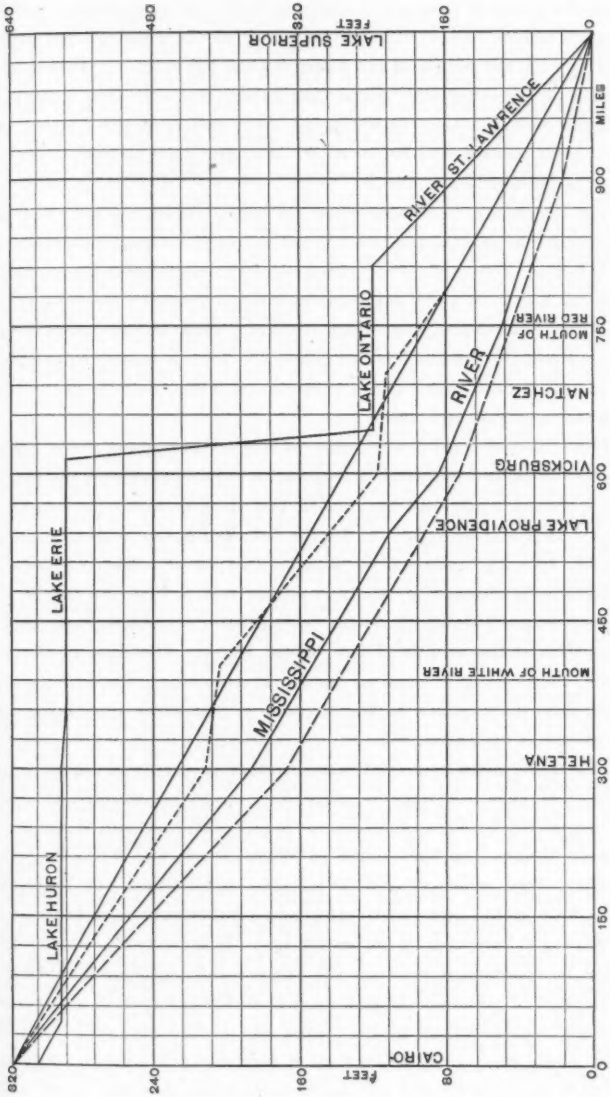

FIG. 5.

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stage, for crests of rises approximating 20 ft. An examination of these actual relations shows that the lowering of the readings has varied directly with the period of low water at Lake Providence. By a similar process of reasoning with the actual gauge relations that existed in 1872 and 1875, the years in which the river remained the longest and least times respectively below 10 ft. at Cairo prior to 1882, a similar result is obtained.

The conclusion is obvious that low-water conditions can eliminate or obscure the results due to high water, but if actual gauge relations prior to and after 1882 are compared, it will be seen that the same forces acting in a river at a low stage can now cause a greater lowering of the gauge at Lake Providence than formerly, while at the mouth of the White River the influence is not as great. This is clearly exemplified by comparing the actual gauge relations of 1893 and 1872, and of 1875 with those of 1890 and 1891.

If the actual relations existing as a river is passing from a high to a low stage are compared, no relation is apparent between the height that a gauge reads and the period the river is above an overflow stage, but it will be found to bear a definite relation to the length of time the river is passing from high to low water. The influence of high stages is obscured by medium stages, but, as with low stages, the medium stages produce in recent years greater results at Lake Providence than at the mouth of the White River. The lines of the diagrams, therefore, give residual results, and are true indices of changes which have taken place in the regimen of the river since levee construction has been resumed.

If a 20-in. main conveyed water from a reservoir at Cairo to the Gulf of Mexico, a hydraulic grade line would be established which is represented by the right line in Fig. 5. If, however, the sections between Helena and the mouth of White River, and Vicksburg and Natchez, were removed, and 30-in. pipe substituted, the hydraulic grade line would not remain the same, but would take some such position as is indicated by the broken line. In a river, the same results would be attained, if between the same localities there had been a diminution in resistance to flow such as would occur from an increase in area of cross-section; at the upper end of the improved reach the water would move away faster than it formerly did, while it could not escape from the lower end any faster until it had acquired head suffi-

cient to overcome the resistance in the unimproved portion below. The rise in plane noted at the mouth of the White River and at Natchez is just as indicative of relative reduction in resistance to flow and possible enlargement of section as the fall in plane at the other stations, but it shows whatever enlargement has taken place in the river has only been partial; that some reaches have been more affected than others. If the remainder of the 20-in. pipe were replaced by 30-in., the hydraulic grade line will then change from the broken line back to the straight line. The 30-in. main will be under exactly the same pressure at every point as was the 20-in., but it will discharge into the Gulf much more water; similarly, if a river were connected with a large lake at Cairo, and its channel were uniformly enlarged, the result would be to discharge more water, but the hydraulic grade line would be unaffected. Mr. Townsend.

It may be objected to this process of reasoning that there is no lake at Cairo, and that the straight line is not the hydraulic grade line of the Mississippi River. The writer has plotted on the same figure the flood heights at the different gauge stations in 1893, and connected them by a line which will approximately represent the existing hydraulic grade line of the river during floods. The reason this line does not conform to the right line in the diagram is because there is not a uniform resistance to flow from Cairo to the Gulf. As explained in the paper, in the lower portions of the river the channel offers less resistance to discharge than above. Returning to the illustration of a pipe line, the large pipes have been concentrated at the lower end of the river. In a river system where the sections offering the least resistance to flow are at the upper portions of the river, as exists in the St. Lawrence, the hydraulic grade line assumes a position concave to the axis of distances instead of convex, as is the case with the Mississippi.

It is extremely desirable to reduce flood heights from Helena to the Gulf, that is, to establish a grade line represented by the lower broken line in the diagram, but it is self-evident that to attain such a result, the slope from Cairo to Helena must be increased to compensate for the reduction in slopes below Helena, if the river attains the same height in the two cases at Cairo. To obtain such a result, the river must remain as it is from Cairo to Helena, and be allowed to enlarge its channel, if possible, from Helena to the Gulf. If an opposite

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course is pursued, and the river is enlarged from Cairo to Helena faster than it enlarges below, then the slope between Cairo and Helena will diminish, more water will be delivered at Helena than the unimproved river below can carry off, except under increased head, and the relative gauge readings in the lower river will be increased.

The approximate hydraulic grade line of the St. Lawrence River from the mouth of Lake Superior to Montreal is added to the diagram to illustrate what would result if resistance to flow from Cairo to Vicksburg was reduced to a minimum and concentrated between Vicksburg and the Gulf, if the effective head which exists at Cairo could be delivered at Vicksburg.

The only other assumption requiring examination is that the river might retain the same height at Cairo if its channel should be enlarged. During low water it is evident that it could not. Under present conditions all the water is discharged at Cairo that is received; if not, the river would rise. If, however, the lower river was enlarged and the resistance to flow diminished, it would discharge a greater quantity of water under the same head than at present. To supply this discharge would require greater velocities in the upper rivers than now exist, which could only be obtained by increasing the slope, viz., by lowering the Cairo gauge. During high water a very different state of affairs exists. This enlargement of section from Helena to Cairo is to result from the construction of a levee line, which will prevent the inflow of water into the St. Francis Basin, and in order to reduce flood heights at Cairo, there must result an enlargement of channel section which will compensate for the unrestricted flow of the crests of flood waves into a basin 40 miles wide, containing an area exceeding 6 000 square miles.

The author proves that higher rather than lower flood heights are to be apprehended at Cairo with a completed levee system. The gauges indicate the same thing. The levee construction in the basins below the mouths of the Red and White Rivers and below Helena have not been accompanied by lower readings of the gauges at those localities during flood stages.

The essential element it is sought to emphasize by this discussion is that the height water will attain is primarily a function of the effective head to which it is subjected; that in a pipe, a sewer, a big ditch or a little ditch, if the pressure on opposite sides of a water film are equal in the different cases, it will rise to the same height independent

of the area of the section or the character of the surrounding medium. Velocity of discharge can not affect flood heights, except by influencing the effective head, and this is a function of the relative velocities above and below the discharge section, rather than the mean velocity of the entire river. Mr. Townsend.

Electrical engineers have a tendency to compare electricity to water. Hydraulic engineers can much more profitably reverse the process, as the electrical engineer has solved many of his mathematical problems, while the hydraulics of rivers shows only an array of failures. The electrical formula, $C = E \div R$, gives promise of better results when applied to rivers than any modification of $v = c\sqrt{r\,s}$, though trouble will probably be experienced in determining R. With an electrical current, by increasing the size of the wire, thus reducing the resistance R, the quantity of electricity discharged is greater; if the size of the wire is so increased as to short-circuit the battery, the electromotive force rapidly runs down. In a river, an increase in cross-section increases discharge as long as the head can remain constant, but a large increase in cross-section short-circuits our battery and reduces the head. That is what takes place in an unleveed basin during floods.

The heights attained by floods at the different stations have been plotted in Fig. 4, and the curved lines inclosing them show the maximum limits that floods have attained at the different stations under varying heads at Cairo. At all the stations prior to 1882 there was a tendency of these limiting curves to become tangent to some horizontal line; that is, with the river unrestrained there is a certain height that cannot be exceeded at the station, no matter what height the river attains at Cairo under the conditions which have heretofore existed. This cutting off of extreme flood heights that is so noticeable in the different diagrams is attributable to the reservoir capacity of the different basins. Their influence may be compared to that of a standpipe in a water system, or of the air-chamber of a pump, which tends to equalize the variations of pressure. The greatest pump pressures can not be transmitted beyond the air chamber.

The curves limiting the floods since 1882, in all cases except Vicksburg, show a rise, and the tangency to horizontal lines is also less apparent, that is, levee construction, by reducing the reservoir capacity of the river, has already markedly raised flood heights. As the reservoir capacity of the basins is still further reduced, these limiting curves

Mr. Townsend. will still more closely approach the line of gauge relations below the overflow stage, and if the reservoir capacity be reduced to that of the river channel, these curves will either correspond to the lines of gauge relations below the overflow stage, or pass beyond them, for it must be borne in mind that the lines below the overflow stage express mean conditions, while those above that stage express maximum.

It is difficult to predict what the people of a district are going to do, but as most of the land under cultivation in the St. Francis Basin is close to the river bank, the temptation of the levee boards will be great to repeat the methods of the lower districts, and place their levees as close to the river banks as possible, restricting the reservoir capacity of the river practically to that of its channel. Under such conditions the line of gauge relations below the overflow stage may be expected to be extended to the extreme height attained by the flood at Cairo.

The changes which have taken place in the relations existing between gauges at stages varying from 35 to 40 ft. confirm both the deductions which have been presented as to changes in gauge relations below the overflow stage, and also during floods. In discussing the gauge relations which exist below the overflow stage these gauge heights were omitted, as they are affected not only by changes in the channel but by the escape of water through sloughs or bayous below the overflow stage, a rather indefinite expression when applied to the Mississippi River. They have been added to the diagram of gauge relations (Fig. 4), however, the mean value prior to 1882 being represented by a dot, since 1882 by a dot inclosed in a circle. Wherever the gauge relations, both above and below the overflow stage, show a rise in plane since 1882, as at the mouth of the White River, a marked rise in the mean gauge relations between 35 and 40 ft. obtains. If, however, there is a lowering of the plane below bank-full stage, accompanied by a rise in plane above, as at Helena and Vicksburg, very little change occurs in these intermediate gauges. At Lake Providence a lower mean-gauge relation is found since 1882, but markedly less than occurs between 30 and 35 ft. on the gauge. At the mouth of the Red River where little change in gauge relations occurs below the overflow stage, the rise in plane of these gauge relations is especially marked. At Natchez the same law is observable, but less pronounced than in any of the other cases.

The author has discussed the influence of the reservoir capacity of

the river channel on discharge. Combined with slope it also produces marked influence on gauge heights, variations of 3 ft. from the mean gauge relations being not infrequent, and the gauges indicate the conditions favorable to a lowering of gauge readings from these causes. These are, a rapid rise at a period when the lower river is at a low stage, followed by a rapid fall; but if the conditions are reversed, if the lower tributaries happen to be high when a gradual rise appears at Cairo, the influence of the reservoir capacity of the river is slight. Mr. Townsend.

It has been argued that because the maximum discharge in the river channel at Lake Providence in 1893 exceeded that at the same locality in 1882 by 50%, with an increase of flood height of 3½ ft., that 100%, or the entire flood discharge of the Mississippi River in 1882, could be carried by Lake Providence with a further increase of 3½ ft. Under favorable conditions such might possibly be the case, but the levee engineer is not seeking favorable conditions; it is the unfavorable that worry him. After a night spent in watching his levee line while a wind is driving waves over the tops of his levees, he views with considerable relief a bright, calm morning. He desires to know, not the least height at which a given discharge will pass, but the maximum height which is to be apprehended under the most unfavorable conditions that are liable to occur.

From the preceding discussion of gauge relations the writer arrives at practically the same conclusions that the author obtains by discussing discharge observations; that existing levees are far too weak to resist a great flood in a river restrained from Cairo to the Gulf; that with the reservoir capacity of the St. Francis Basin undiminished floods are liable to occur which will strain existing levees to their utmost capacity, and that the influence of enlargement of section on flood heights will be local. The danger, however, to the inhabitants of the lower basins is not as imminent as this discussion would appear to indicate. It is a safe prediction from experience with other basins that the next great flood will not be entirely prevented from entering the St. Francis Basin. There is also a safety-valve at the head of the Tensas Basin which will prevent abnormal flood heights below. An increase in flood heights at Arkansas City will be accompanied by a discharge around the head of the Tensas levee system. Before the gauge could record 56 ft. the area of the waste weir would equal that of the discharge section, though obstructed by forest growth.

Mr. Starling.

WILLIAM STARLING, M. Am. Soc. C. E.—Since the publication of the paper, the author has received several interesting communications bearing on the history of river gauging in the United States. The earliest example of a telegraphic meter, and also the first instance of a meter of the anemometer type, was the device of D. Farrand Henry, M. Am. Soc. C. E., then United States Assistant Engineer in the service of the Lake Survey. In 1868, Mr. Henry constructed a current meter out of an old Robinson's anemometer, and adapted to it a recording apparatus consisting of a break-circuit arrangement and a Morse register. He also used a meter of the screw or propeller type, with an electrical connection, and thought it the preferable form. With these instruments a large number of very interesting observations were made on the St. Clair and Niagara Rivers. Among others, an extensive series of measurements was carried out to determine the distribution of velocities in vertical planes, with the primary intention of finding out a coefficient for double floats, in the use of that method. The results of these measurements agreed well among themselves, but were quite different from those obtained by floats, and the curve of vertical velocities did not correspond to the parabola of Humphreys and Abbot. In the "Reports of the Chief of Engineers" for 1868 and 1869, and again in the report for 1870, Mr. Henry gave an account of these experiments and his reasons for preferring the meter to double floats. These reasons are given in detail in the pamphlet published by him in 1873,* which contains a valuable summary of the engineering knowledge at that date on the subject of the distribution of velocities in vertical planes, and also on that of the rating of meters.† These observations were referred by the chief of engineers, General Humphreys, to General Abbot, and were reviewed by the latter with much asperity.‡ Mr. Henry replied in a similar tone in a supplement to his pamphlet, wherein he maintained his position with ability, and gave some interesting observations on the theory of double floats, by which it would appear that at considerable depths they must always give a velocity in excess of the true rate.

The rating of these early instruments was performed very much as at the present day. The rating line found, as had been observed by

* "The Flow of Waters in Rivers and Canals," by D. Farrand Henry, Chief Engineer Detroit Water-Works, Detroit, 1873.

† See also the "Report of the Chief of Engineers" for 1870, p. 551.

‡ "Report of the Chief of Engineers" for 1870, p. 616.

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Baumgarten and Boileau, was a curve, which, at high velocities, became almost a straight line.

The Ellis meter afterward used (in 1874) was constructed on the same principle as the anemometer meter of Mr. Henry, to whom, indeed, General Ellis acknowledges his obligations. It was used in conjunction with a meter of the Woltmann type. Both were rated by the equation of a straight line. Both the observations of Mr. Henry and of General Ellis* are well worthy of the attention of those who are interested in this part of hydraulics.

During the month of October, in 1879, a notable series of observations was made on the upper Mississippi, near Burlington, Ia., under the direction of Alexander Mackenzie, M. Am. Soc. C. E., by G. A. Marr, M. Am. Soc. C. E. This work appears to have been executed with much care and thoroughness. Six meters were used at once, placed at equal distances apart on a wire cable, suspended from a derrick which projected some 20 ft. in front of the bow of an anchored boat. The depth of water varied from 11 to 27.6 ft. The details of the processes pursued will be found in Colonel Mackenzie's report, published several years afterward.†

An interesting fact, established both by Mr. Henry's and Mr. Marr's observations, is the existence of very decided pulsations of the current, alluded to in the paper.‡ Mr. Henry found lesser fluctuations of half a minute to one minute in duration, with maxima every five or ten minutes. They did not seem to be synchronous with the oscillations of the surface level, which were also very irregular. "Often," says Mr. Henry, "when two floats were put out from the upper boat, one minute apart, the last one would gain upon and sometimes pass the first." It was found that the pulsations were much the greatest near the bottom, where the minimum velocity observed was sometimes less than half the maximum.

The observations are corroborated by Mr. Marr, who also remarks that the changes generally occur at about the same time from the surface to the bottom. In confirmation of these statements, very interesting plottings are given by Mr. Marr. The pulsations are not capricious, but occur with considerable regularity, and with approxi-

* "Report of the Chief of Engineers" for 1878-79, Vol. I, p. 312.

† Report on Current-Meter Observations in the Mississippi River, near Burlington, Iowa, by Major Alexander Mackenzie. Washington, 1884.

‡ *Transactions*, Vol. xxxiv, p. 385.

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mate periodicity. The periods of the major and minor fluctuations correspond closely with those found by Mr. Henry. So also does the amount of the oscillation, which, according to Mr. Marr, is sometimes nearly half the greatest velocity, in less than one minute of time.

The value found by Mr. Marr for the relation between mean and mid-depth velocity is exactly the same as that reported in 1882 at the stations on the lower Mississippi, viz., 0.958. General Ellis found it 0.940. The ratio of the depth of the fillet of mean velocity in vertical planes to total depth is 0.622, against 0.63 in the lower river. Mr. Henry had found it to be about 0.6. General Ellis had given it as 0.636. Mr. Price has remarked that the observations of 1882 cannot be implicitly relied on at some of the stations. This is doubtless correct, yet the mean results may probably be accepted as fair approximations.

Professor Spalding takes a somewhat sanguine view of the situation on the lower Mississippi, with which service he was once connected, and thinks that the estimates given in the paper of flood heights eventually to be attained may be excessive. This is the earnest hope of all who are engaged in the levee service, and there is some ground for it. Observation so far as it goes, is indecisive, having been continued for so short a time. A few words will be said on this point hereafter.

Professor Spalding thinks that a straight line may be made to fit the ratings of meters within the ordinary errors of observation. Perhaps it could, yet it would be but a misfit after all. Because there are errors which are unavoidable in observation, it does not follow that additional mistakes should be voluntarily incurred by faulty methods of interpretation. It is shown by Mr. Price in his discussion of the paper that the equation of the rating curve varies with the form of the wheel. Mr. Henry found the curve to be an ellipse whose axes were 8.28 and 3.44, respectively. Mr. Marr found it to be a straight line.

Mr. Crowell's remarks about the diminution of velocity in the stream by the transportation of sand and gravel are doubtless correct, though it is not easy to estimate this influence quantitatively. It is thought, however, that this should not be confounded with viscosity. There is no such thing as "thick mud" in the flowing water of the Mississippi, the quantity of matter in suspension being probably never sufficient to impair the fluidity of the water to an appreciable extent. The highest recorded ratio, by weight, of sediment to water is 1 to 195, or something more than half an ounce to the gallon. This is a solitary

case. The next highest is 1 to 549, or about a fifth of an ounce to the gallon. In the Missouri, the remarkable proportion of 1 to 37 has been observed, or nearly 4 ounces to the gallon. Mr. Starling.

Mr. Dabney calls attention to the omission by the author of the effect of bank erosion on the load of sediment carried by the stream, and its influence on bar-building. The point is very well taken. There seems to be no question that the material which goes to form troublesome shoals is very largely derived from the caving reaches in the bends or pools above, and this effect should be added, in many situations, to that of the regular scour which takes place during every flood in the deep places. In other instances, the erosion of the bank seems to be merely the consequence of what is taking place on the bottom. It is the latter which scours, and the bank falls in, being undermined, to replace the material which has been removed from near its base. On the other hand, at low water, it is the shoal which cuts out, and this cutting out is often confined to a narrow section near the bank*, inducing a low-water cave. In the case of the discharge sections quoted in the paper, there were no caving banks of any consequence in the vicinity, the sections being chosen partly on account of their freedom from this disturbing influence.

Mr. Harrod's remarks on the effect of the confinement of the flood waters by levees upon the low-water line are in strict consonance with the evidence. The progressive decrease which has been observed since 1890 of the gauge readings below Cairo still continues, the low water of 1895 having been about 1 ft. below that of 1894, which was itself the lowest on record up to that time, from Memphis to Vicksburg. By those dependent on levees, the steady decrease of low-water heights is very naturally attributed to the confinement of the flood discharge with which it was coincident in time; and this the more that such a result had been anticipated by them as a consequence of the completion of the levee system. In this view the author is inclined to concur; yet, as Mr. Harrod says, the period of observation is too short to allow of a positive conclusion, and there are other agencies which might have had a potent effect in producing the phenomenon in question. One of these is the very prolonged period during which low water has prevailed for the last three or four years. The average length of the period of low water, during which the river has been below the stage

* *Transactions*, Vol. xxxiv, p. 472.

Mr. Starling. of 12 ft. on the Helena gauge, is 97 days. The greatest periods have been, in 1872, 165 days; in 1874, 135; in 1886, 131; in 1887, 170; in 1892, 110; in 1893, 175; in 1894, 177; in 1895, 265 days. The natural tendency of the low-water stage is to cut out the bars, and this process would reduce the low-water line as effectually as a general enlargement of the cross-section.

Though the low-water mark be reduced in height between tributaries, whether by cutting out the bars or by enlargement of the section, yet it does not necessarily follow that the high-water line must be lowered. If there be an increase of section in the direction of width, and at the same time a decrease of mean depth, which is perfectly compatible with an increase of maximum datum depth, the flood-line may not be reduced in height at all. Mr. Harrod has shown* that the net result of continued caving is an increased width of river; and Captain Townsend's surveys of the Lake Providence Reach in 1891† seem to point in the same direction.

While all levee engineers, therefore, hope for a reduction of flood-heights as a consequence of the confinement of the waters of the river to its channel, and while they think they have good grounds for such a hope, they do not like to be too sanguine of such a result, and they are certainly not justified in relaxing their efforts on the faith of such a prospect.

Mr. Price thinks that the cleaning of a meter or the oiling of a bearing has but little effect on the rating. The opinions expressed in the paper were derived from the experience of observers. At Point Pleasant, in 1885, on February 3d, the meter, when turned by hand, took 78 seconds to come to rest. On the 5th of February it required 170. The explanation given is that the cup containing the electrical connection had been filled with oil in the meantime. On March 27th a new contact apparatus was put on, changing the time required to come to rest from 185 to 265 seconds. In 1891, at Wilson's Point, it was found that the rates of the same meter were very different. In seeking to explain these differences, Mr. T. C. J. Baily writes:‡

"The larger values of the coefficients a and b for Meter No. 5 found at Huntington from those found at Wilson's Point I think are

* Paper on the protection of banks, in the "Report of Mississippi River Commission" for 1885, p. 2885.

† "Report of the Mississippi River Commission" for 1893, pp. 3786-3806.

‡ "Report of the Mississippi River Commission" for 1892, p. 3124.

due to the fact that at the former place only the lower bearings were oiled, for fear of injuring the electrical connection, while at the latter place both bearings were oiled. * * * I have found that the stiffness of the oil used has a marked effect upon these coefficients. * * * A very marked difference appears in the rate of Meter No. 5 after it was reported as being thoroughly cleaned." Mr. Starling.

Indeed, it might be inferred from Mr. Price's own remarks that friction plays an important part in determining, not indeed the form of the curve, but its position with reference to the origin of co-ordinates, or the constant *b*. However, this is a subject on which Mr. Price ought to be classical authority.

Mr. Miller's remarks on the advisability of selecting wide rather than narrow places as discharge sections are worthy of attention, especially as proceeding from an observer of long experience. What he says about the change of location of the sections at Arkansas City and at Wilson's Point in 1893 may partially explain some of the discrepancies which had been observed at those points in previous years.

Mr. Coppée's instance of a remarkable pulsation of the flow of the river corresponds to the experience of all engineers who have had occasion to observe the behavior of the Mississippi or other large streams in this respect. Any one who undertakes to get the reading of a gauge, even on a still day, will find that the water level is in a state of continual fluctuation, and it is well nigh impossible to define it with precision. These fluctuations do not necessarily correspond in time, as Mr. Henry has remarked, with the pulsations of velocity.

Professor Johnson thinks the study ought to have been carried a little farther, and desires estimates of the heights to be attained in other portions of the river. In most investigations made by practising engineers, it is not the mere abstract love of scientific truth that is the impelling motive, but some immediate need. In the present instance, the object sought was to fix the ultimate grade of levees in the author's district, of which Arkansas City and Wilson's Point are principal stations. The investigation was not extended further, principally from the lack of personal familiarity with the local conditions existing elsewhere, and from the great additional expenditure of labor and time which it would have involved. It was thought that if the methods pursued in the paper stood the ordeal of criticism and appeared to be

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sound, the scope of the investigation could afterward be extended so as to embrace other parts of the river.

At Red River the situation seems to be very complicated. That stream has acted, at different times, both as an inlet and as an outlet. It was formerly the principal channel through which overflow waters from the Tensas Basin were returned to the Mississippi. Testimony as to the facts is not harmonious. The majority of the Mississippi River Commission think that with the exclusion of the return flow from the Tensas Basin consequent on the complete closure of that front by levees, Red River would act as an outlet, and that the shutting-off of it would cause a considerable increase in the discharge to be carried by the Mississippi below its confluence.

On the other side, Colonel Suter, who has been studying the Atchafalaya problem for twelve years or so, maintains that the flow from Red River into the Mississippi is "the great factor in disastrous floods in lower Louisiana, whether the water producing this inflow be crevasse water from the Mississippi or the drainage from the Red River Basin." "The Atchafalaya," he continues, "never has acted as an outlet in great floods, and I do not believe that it would do so, even if the crevasse water were excluded, as the Red River is invariably in flood at such times."

One would not care to give an opinion on such a vexed and important subject without careful study and a personal familiarity with the facts and the localities, which is not possessed by the author.

Mr. Hider's detailed account of the methods taken to insure accuracy in the practical work of measuring the discharge is very instructive, and shows conclusively that it was not the fault either of the instruments or of the men that discrepancies occurred between the discharges reported at two adjacent stations. The candor with which these discrepancies were reported and published, without any attempt to cook them, is an excellent evidence of the true professional spirit which actuated the engineers engaged. The method of integration in a horizontal plane, proposed and executed by Mr. Hider, is one that seems to have the elements of great promise in it. The greatest drawback to it is the necessity of an assumption of a regular distribution of velocities in vertical planes. Some such assumption is necessary, however, in most of the methods which have been yet employed.

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Captain Townsend's discussion brings into the field the interesting but not at all simple question of the enlargement of section of a more or less permanent nature and of a general kind, and the resulting influence on gauge heights at low water and in flood. The paper has barely touched this subject, partly because the evidence, so far as it is published, is scanty; and partly because the testimony of the gauges does not show any material alteration in the position of the flood line at the points where the enlargement is known to have occurred. The evidence adduced by Captain Townsend of the changes brought about in the gauge relations at low and medium stages appears incontrovertible. These changes, however, seem to be confined mostly to such stages. At Helena, for instance, Captain Townsend shows * that at low water the gauge at Helena, as compared with Cairo, is 2 ft. lower since 1882 than before that time. So, also, the crest of a rise reading 30 ft. on the Cairo gauge passes Helena at least 2 ft. lower after 1882 than before. Captain Townsend's tabulations extend no higher than about 35 ft. The author has carried them up to 40, at which stage overflow barely begins. At stages between 35 and 40 ft., it is found that the Helena gauge, prior to 1882, stood at an average of 0.84 ft. above the Cairo gauge, since 1882 at an average of 1.06 ft. above, showing that under these circumstances the crest of the wave now passes Helena at a slightly higher stage than formerly.

It does not seem very profitable to compare Lake Providence with Cairo, for the two great southern tributaries, the White and Arkansas Rivers, intervene, and pour out floods which are sometimes of enormous volume, and are so variable and capricious, and influence gauge heights below them to such an extent (sometimes several feet) as to obscure altogether the ordinary relations. It would be very proper, however, to compare Lake Providence with Arkansas City, which is below the mouths of the tributaries. Gauges have been kept at Arkansas City only since 1880. Since that time the relations between this point and Lake Providence have been as shown in the table on page 366.

The figures represent the differences between the gauge readings at the crests of rises at Arkansas City and Lake Providence, Arkansas City being the higher.

* "Report of the Mississippi River Commission" for 1894, p. 2972, Table No. 2.

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RELATION BETWEEN GAUGE HEIGHTS AT ARKANSAS CITY AND LAKE PROVIDENCE.

Year.	0-10	10-20	20-30	30-35	35-40	40-45	45-50
1880....	+0.30	+3.0	+3.45	+4 30	+4.92	+3.95	+7.25
1881....	.....	.....	6.20	5.15	6.15	7.23	.....
1882....	1.40	2.01	3.65	.....	.....	7.74	8.85
1883....	.....	2.87	4.47	4.98	.....	7.95	9.83
1884....	3.87	3.87	5.08	5.20	6.00	7.65	8.35
1885....	.....	3.18	5.86	6.62	6.68	7.00	
1886....	1.21	2.14	5.74	6.00	6.62	7.20	8.99
1887....	0.24	4.26	5.46	.....	7.16	.....	8.65
1888....	.....	.....	5 96	6.37	6.90	.....	7.27
1889....	.....	3.67	5.45	6.61	6 78	.....	
1890....	.....	3.57	5.6	.....	5.9	.....	7.4
1891....	0.2	5.9	5.2	6.5	.....	.....	6.7
1892....	2.8	5.9	6.2	.....	.....	.....	7.0
1893....	3.3	4.8	5.7	.....	6.4	.....	7.2

The principal change which has occurred in the regimen of this part of the river since the beginning of the period embraced in the table is the rebuilding of the Arkansas levees in 1887. The effect of this work is seen plainly in the last column of the table, which shows the differences between the gauges at very high stages. This difference has been considerably reduced since 1887, from the confinement in the channel of large volumes of water which formerly escaped over the bank between Arkansas City and Lake Providence. It should be observed that the figures given in the last column, for the years since 1887, do not represent the actual difference between the heights of the crests of the rises at such times as there were breaks in the levees between Arkansas City and Lake Providence. Such a comparison would be of little profit or interest. The differences given are those existing at the time the first crevasse occurred, in each year, with a suitable time correction to allow for the passage of the crest from the one station to the other. For instance, in 1892, the first crevasse took place on May 9th, between Arkansas City and Lake Providence. On that day, the reading at Arkansas City was 48.8, and the river was nearly stationary. At Lake Providence the gauge was 41.6, and rising at the rate of about 0.1 ft. a day. It takes about a day and a half for the crest to pass from the upper to the lower station. Therefore the reading at Lake Providence corresponding to 48.8 at Arkansas City would have been about 41.75. So in 1893, the first break occurred on May 11th, between Arkansas City and Lake Providence, the gauge at the former station reading 49.0 and at the latter 41.4.

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The river was rising at the rate of about 0.3 ft. per day. It is therefore inferred that about 0.45 should be added to the reading at Lake Providence to get the difference which would have prevailed for a crest of the given height. This would give 41.85, or a difference below Arkansas City of 7.15. By another process it was estimated that the stage at Lake Providence, at the height of the rise in 1893, would have reached about 42.8, if there had been no crevasses below Arkansas City. This would give a difference of about 7.4.

It is thought that these facts substantiate the position taken in the paper that "the relation between the gauges at Arkansas City and Lake Providence seems to have undergone no considerable alteration since 1885."

The table of maximum discharges at Lake Providence given by Captain Townsend for the different flood years in which they were measured, with the statement that an increase of discharge of 440 000 cu. ft. per second has been accompanied by a rise in gauge height of only 3.5 ft. requires some comment. It is well understood that Captain Townsend is not responsible for these figures nor for the inference that 3.5 ft. more would carry the whole discharge of 1882. It would be very pleasant to entertain this belief if there appeared to be solid grounds for it. It is feared, however, that it will not stand examination. The discharge of 1 057 000 cu. ft. at Lake Providence in 1882 was carried, not at the maximum stage of 38.32, but at 34.85, nearly three months later. There was carried indeed a discharge reported as 936 954 cu. ft. at the highest stage, but this was just at the time of the great return flow at Vicksburg,* whereby the slope Lake Providence-Vicksburg was reduced from the ordinary high-water slope of 0.30 ft. to the mile to 0.23 ft., thereby raising the gauge at Lake Providence by the effect of back-water; and moreover the discharge recorded does not include the flow over the banks outside of the discharge section, which was considerable, as the station was a mile or more outside the levee. In June, when the maximum discharge of 1 057 990 cu. ft. is recorded, the slope was exactly the normal for that stage, namely, 0.301 ft. to the mile, and there was no discharge worth mentioning over the banks. Hence the stage, 34.85, might properly be taken as corresponding to that discharge. The velocities were taken with meters. So in estimating the greatest discharge ever passed

* See *Transactions*, Vol. xxxiv, pp. 478 and 479.

Mr. Starling. within banks, that of 1893, it would not be proper to take the height actually attained, 41.8, reduced as it was by four considerable crevasses, all within the distance of 45 miles above Lake Providence, and apply to it the discharge obtained by adding to the observed discharge the flow through those crevasses. It would be more reasonable to take the stage and the discharge observed just before the first crevasse. These were 41.4 and 1 400 398. There would thus be an increase of discharge of 342 408 cu. ft. for 6.55 ft. of rise of the river. This result would be far nearer to the truth, yet even this would not be accurate, for the gauge relations between Lake Providence and Greenville, 64 miles above, in 1882, show that there was a disturbance at the former place, due to loss of water over banks and through crevasses either between Greenville and Lake Providence or below Lake Providence or both. It is useless to attempt to estimate these perturbations because there are no data sufficient for the purpose. Indeed it is time lost to reason from such premises at all.

Captain Townsend's inference, from accessible data, that general enlargement of the section at Arkansas City occurs during great flood years, and that contraction of the section attends years of low water, and especially a succession of such seasons, appears consonant to probability. It is not impossible that these changes are general throughout the river. There are some indications that such may be the case. If this be borne out by accurate and long-continued observation, it will lead to very interesting conclusions. If there is a general fill throughout the river during a succession of low-water years, it must proceed from the contributions of solid matter brought down by the tributaries, and it would appear plain that the main river, at such times, had not sufficient transporting power to carry to the sea these accessions of sediment; while in years of flood it had a superfluity of power, enough to remove the accumulations of previous years and perhaps to make new inroads on the banks and bottom. This would conform to the general idea that sedimentary streams enlarge their beds if they have to carry increased volumes; and that, on the other hand, as Captain Leach expresses it, that they will not tolerate beds which are too large for them. It would be very instructive to examine into the connection, if any, which these phenomena have with the stages of the Ohio. Great floods have usually proceeded, for the most part, from this stream, which is, comparatively, a clear-water river. Again,

even during low-water years, there have usually been large accessions, both of water and of sediment, from the Missouri and other muddy streams. Mr. Starling.

The diminished section at Arkansas City in 1879 and in 1889, to which Captain Townsend refers, might be accounted for by the ordinary fill in pools in low water; but this would not explain the high stage at which the discharge passed in 1889, or change of plane, which would indicate a fill on the bar as well as in the pool.

The enlargement of section at Wilson's Point seems to be well established. The following are the extreme measurements of the datum area from the earliest observations:

1884	172 129 to 195 504
1885	180 333 to 198 438
1887	191 139
1888	174 672 to 188 075
1889	164 648
1890	157 707 to 194 422
1891	191 391 to 222 272
1892	203 029 to 233 659
1893	197 988 to 229 292

It would thus appear that the datum area at this point has increased since 1884 some 25 000 to 35 000 sq. ft., and that most or all of this has occurred since 1890; and by far the greater part during the interval between the floods of 1890 and 1891. Notwithstanding this, the high-water gauge relations between Lake Providence, 11.1 miles below Wilson's Point and Arkansas City, where the section is nearly the same as in 1884, are almost or quite unaltered. In other words, the high-water discharge passes at about the same height as it would have done had there been no enlargement of section; and the increase of area is accompanied by a diminution of velocity. This is incompatible with a general enlargement of section below Arkansas City, unless it be entirely in the direction of width, and be attended by a decrease of mean depth, which indeed seems probable.

As Captain Townsend says, the levee engineer cannot afford to depend upon favorable conditions; it is the unfavorable that trouble him, and it is against these that he is bound to provide.

Mr. Starling. The views expressed relative to the changes to be produced by the leveeing of the St. Francis Basin seem to be sound. As this will soon be an accomplished fact, there will be an opportunity to bring the reasoning to the test of fact.